Communication from Public

Name: Warren Resources, Inc.
Date Submitted: 11/21/2022 04:44 PM
Council File No: 17-0447-S2
Comments for Public Posting: Dear City Council Members, Please see the attached written comments on Agenda Item No. 32 of the November 22, 2022 City Council Meeting - Proposed Mitigated Negative Declaration, ENV-2022-4865-MND Regarding Proposed Amendments to the City's Oil and Gas Ordinance. It is astonishing that the City ignores black-letter law under CEQA in attempting to adopt Mitigated Negative Declaration, ENV-2022-4865-MND (MND) in connection with the Project to phase out oil and gas operations in the City. Warren objects to the City's adoption of the MND and the associated documents and actions described in Agenda Item 32 relating to the Project. These objections to the City's proposed actions are described in detail in the attached documents, including our letter dated October 17, 2022, and these documents are incorporated herein by reference. It is emblematic of the City's apparent disregard for public comments that the PLUM Committee report, along with notice that this action was on the City Council agenda for November 22, 2022, was posted to the City's Council File Management System after business hours on Friday, November 18, 2022, going into Thanksgiving week. In other words, the City gave the public one business day to prepare and issue comments for this hearing. The City further ignores the law with regard to expert opinion submitted by Warren that the action will result in a significant effect and thus require an EIR. The City appears to defend its actions by stating that it disagrees with Warren's air quality experts, Yorke Engineering. The law is clear, however, that "[i]f, after evaluating the evidence . . . qualified experts disagree about the likelihood of an environmental impact or its magnitude, the agency must assume that a significant impact may occur and must prepare an EIR." City of Carmel-by-the-Sea v. Board of Supervisors (1986) 183 Cal.App.3d 229, 249. We appreciate your time and review. Sincerely, Warren Resources, Inc.

DAY ▪ CARTER ▪ MURPHY LLP

3620 American River Dr., Suite 205
Sacramento, CA 95864
T: 916.570.2500

daycartermurphy.com

Thomas A. Henry
thenry@daycartermurphy.com

November 21, 2022

VIA ONLINE PUBLIC COMMENT SUBMISSION
[cityclerk.lacity.org/publiccomment/]

Los Angeles City Council
200 North Spring Street
Los Angeles, CA 90012

Re: *Agenda Item No. 32 of November 22, 2022 City Council Meeting - Comments on Proposed Mitigated Negative Declaration, ENV-2022-4865-MND Regarding Proposed Amendments to the City's Oil and Gas Ordinance*

Dear City Council Members:

This firm represents Warren E&P, Inc.; Warren Resources of California, Inc.; Warren Resources, Inc.; Warren Management Corp.; and Warren Operating LLC (collectively "Warren").[1] On behalf of Warren, we are providing these comments in opposition to those recommended actions for adoption as described in the Los Angeles City Council Agenda dated November 22, 2022, at Agenda Item 32, 17-0447-S2 (Agenda Item 32), and concerning those actions related to the City's proposed adoption of an amendment to Los Angeles Municipal Code (LAMC) Sections 12.03, 12.20, 12.23, 12.24 and 13.01 (the "Project"). Warren incorporates by reference its prior submissions and evidence to the City, as described in the various attachments included with this letter.

Warren objects to the City's adoption of the Mitigated Negative Declaration, ENV-2022-4865-MND (MND) along with the associated documents and actions described in Agenda Item 32 relating to the Project. As described in our letter commenting on the MND dated October 17, 2022 (attached hereto as Attachment C) the City is legally required to prepare an Environmental Impact Report (EIR) for the proposed Project to amend the LAMC as described in the draft MND.

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[1] Warren operates drilling and production sites within the City and would be detrimentally affected by the Project. It has a beneficial interest that would be adversely affected by the environmental impacts associated with the Project, and the Project will otherwise have a direct, substantial effect on Warren and its operations. Further, Warren makes these comments on behalf of the public interest, which interest would suffer if the City were not compelled to perform its duties under CEQA.

Both supporters and opponents of the proposed change to the LAMC have pointed out multiple deficiencies in the MND. Accordingly, it is unclear why the City is disregarding the problems with the MND and rushing forward with a legally inadequate document, which was first released to the public on September 15, 2022—just a week before the Planning Commission meeting to review and recommend approval of the MND. The City's actions were so hurried that it did not even give the required thirty days for the public to provide comments on the MND before the Planning Commission recommended that the City Council adopt the MND along with various findings related to environmental impacts associated with the proposed Project, which findings should have been guided by the MND, public comments on the MND, and responses and revisions made by the Planning Department as part of the complete CEQA process.

It is emblematic of the City's apparent disregard for public comments that the PLUM Committee report along with notice that this action was on the City Council agenda for November 22, 2022, was posted to the City's Council File Management System after business hours on Friday, November 18, 2022, going into Thanksgiving week. In other words, the City gave the public one business day to prepare and issue comments for this hearing.

Notwithstanding the City's apparent disregard of an orderly, methodical environmental review process, Warren provides the following comments:

1. **Differing Expert Opinion Alone Requires the City to Evaluate the Impacts of the Proposed Project Pursuant to an EIR**

As noted in our letter of October 17, 2022, even where there is "disagreement among expert opinion supported by the facts over the significance of an effect on the environment, the Lead Agency shall treat the effect as significant and shall prepare an EIR." CEQA Guidelines, § 15064(g). The City ignores this legal standard by disputing Warren's experts who concluded that the MND's air and GHG impacts analysis suffered from fatal flaws, and that in their opinion the proposed Project would result in significant air and GHG impacts.

Instead of conceding that it needs to prepare an EIR, the City continues to drastically understate both the type of equipment, in particular a mud truck engine, and the horsepower of the drill rig that will be used in conducting plugging and abandonment operations. As noted in the Yorke Engineering report (Yorke Report, attached to our October 17, 2022 comment letter (Attachment C to this letter) and incorporated herein by reference), the MND begins with the flawed assumption that the drill rig used would have a 33 bhp rating. This has caused the MND to drastically understate air impacts, GHG impacts and noise impacts. The Yorke Report noted that the drill rig would have an actual bhp rating of 540, roughly sixteen times the bhp provided in the MND—and that when a correct equipment and equipment rating were analyzed, significant air and GHG impacts would result.[2] The Yorke Report noted that the MND did not bother to analyze health impacts related to the activity. In its response to Warren's comments, the City

[2] The Yorke Report notes that the mud truck engine also has a similar engine to the rig of approximately 540 bhp.

essentially contests the type of equipment and ratings that would be used for plugging and abandonment purposes. Yet, a cursory Google search as to service companies conducting abandonment operations easily indicates that the MND's assumption of 33 bhp is drastically off, and a bhp rig rating of 540 is more likely accurate.[3] In contrast, the bhp used by the City in the MND is roughly the same as a riding lawnmower.[4]

Based solely on this information, the City must develop an EIR under the CEQA standard relating to expert opinions. The standard is not whether the City believes that its experts are correct; it is whether other expert opinion has been provided that indicates a significant impact. "If, after evaluating the evidence . . . qualified experts disagree about the likelihood of an environmental impact or its magnitude, the agency must assume that a significant impact may occur and must prepare an EIR." Ci*ty of Carmel-by-the-Sea v. Board of Supervisors* (1986) 183 Cal.App.3d 229, 249.

2. The City is Clearly Piecemealing the Proposed Project.

Substantial evidence exists in the record that the City is attempting to unlawfully piecemeal a larger project. In our October 17, 2022 letter (Attachment C hereto), we outlined information provided by the City itself that indicates reasonably foreseeable future projects that do not have independent utility but rather are dependent on the passage of the proposed ordinance changes—the first step in multiple steps that the City has promised to address over the next few years. As stated by the City Staff Report at A-2, "there are many other follow up actions that the City will undertake to ensure the safe phaseout of oil operations." Staff Report at A-2 to A-3 (discussing some of the follow up actions).

- The City has stated on multiple occasions that upon completion of the amortization study the law will likely be changed to shorten the amortization period. This change may result in the present MND drastically understating the impacts that would result from wells having to be plugged and abandoned in a shorter or more condensed period.

- The City Staff Report also notes that with regard to remediation this ordinance "represents the first step." Staff Report at P-6.

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[3] See for example information from the following companies that conduct plugging and abandonment work with bhp rig ratings even higher than 540, which information is incorporated herein by reference, https://royaltywellservice.com (describing a 675 bhp rig rating) and http://www.themcdanielcompany.com/services/plugging-abandonment.html (describing average bhp of rigs at 675).

[4] See for example information from the following company, which is incorporated herein by reference: https://adirondackpowersports.com/Lawn-Mowers-Riding-Simplicity-Legacy-XL-Vanguard-Big-Block-Rear-PTO-33-hp-2021-Malone-NY-5ed8aa0e-dbbb-44d6-9b1e-ac5500810c9e.

- The City has also indicated that it will clarify what is precluded as "maintenance activities." Staff Report at P-3.

- As noted in our earlier comments, the California Supreme Court set out the standard for unlawful piecemealing in *Laurel Heights Improvement Association v. Regents of University of Cal.* (1988) 47 Cal.3d 376, 396, holding that "an EIR must include an analysis of the environmental effects of future expansion or other action if: (1) it is a reasonably foreseeable consequence of the initial project; and (2) the future expansion or action will be significant in that it will likely change the scope or nature of the initial project or its environmental effects." The information provided by the City clearly indicates that this is but the first step in further actions to be taken by the City. The further actions do not have independent utility but are part of the plan to phase out oil and gas operations in the City.

3. Multiple Individual Impact Sections Also Are Deficient Because They Fail to Define an Adequate Baseline; Fail, by the MND's Own Admission, to Adequately Analyze Potential Impacts; and Fail to Analyze, or Properly Analyze, Impacts as Described in the City's Own Thresholds of Significance. Accordingly, the City Failed to Proceed in a Manner Required by Law, and Its Review is Not Supported by Substantial Evidence.

The MND contains multiple further deficiencies that must be addressed by the City pursuant to an EIR, including:

- The MND fails to set out a baseline supported by the evidence in the record. An accurate baseline is necessary to analyze the effects of the baseline against the proposed Project. *Taxpayers for Accountable School Bond Spending v. San Diego Unified School District* (2013) 215 Cal.App.4th 1013, 1047-1048. The MND assumes that oil and gas operations are harmful despite the fact that there is no evidence supporting this conclusion. In contrast, Warren has provided evidence in the Yorke Report that its operations are on par with a fast-food restaurant with a drive-thru among other uses.

- The City's analysis as to impacts to the "loss of availability" of mineral resources ignores the explicit standard in both the CEQA Guidelines and in the City's own CEQA thresholds of significance, and instead focuses on things like policies to reduce oil production, and the current production occurring in the City. Again, the standard is the "loss of availability" of mineral resources. The City also ignores publicly available information on this issue, including the expert opinion of the US Geological Society. Indeed, the City's own Oil and Gas Health report confirms that 1.6 billion barrels of recoverable oil exist beneath the City "rivaling the reserves in the Middle Eastern countries . . . ." Surely, mineral resources will be less available as a result of the ordinance amendment and the City cannot simply ignore that impact or the evidence presented by Warren.

- The MND does not describe with any substance the health impacts related to plugging and abandonment operations.

- The GHG impacts analysis is deeply flawed in that it understates the impacts related to plugging and abandonment operations. It also fails to analyze reasonably foreseeable impacts related to extinguishing oil production in the City. In particular, the City ignores the GHG impacts that will result from the rising importation of oil either shipped in from overseas or trucked in from other areas in the United States. It is remarkable that despite having multiple refineries within the area, the City appears to assume that these refineries would not import oil from other sources as production in the City is extinguished.

- The MND's Land Use Planning Analysis is deficient in that it omits City General and Community Plan policies that support the environmentally responsible development of oil in the City. The City cannot ignore these policies and instead selectively identify policies it believes supports its position.

- The City describes mitigation measures without indicating how these vague measures will be enforced.

- The MND understates noise and vibration impacts in that it has failed to adequately describe the equipment that will be used. The City also ignores the fact that such work will likely have to be conducted in a much more intensive manner than described in the MND.

- The City fails to examine any cumulative impacts, and fails to discuss reasonably foreseeable indirect impacts as required by CEQA.

- The MND fails to consider the potential for urban decay as drill sites are abandoned, and describes as "speculative" the indirect impacts that may result from the change in the use of these sites. Simple examination of zoning laws and location would allow the MND to project how these sites will likely be used in the future.

For the foregoing reasons, the City Council must decline to adopt the actions recommended in the November 22, 2022 Agenda. In particular, the evidence indicates that the City must prepare an EIR, and must do so on the whole of the project, not just this first phase of it. If the City fails to do so, it will be in violation of the law and subject to legal action for, among other things, failing to comply with CEQA.[5]

Very truly yours,

DAY CARTER & MURPHY LLP

Thomas A. Henry

TAH:ms
Attachments

[5] Warren incorporates by reference its previous letter to the Planning Commission dated September 19, 2022, a copy of which is included as Attachment A, its letter dated October 5, 2022 to the Energy, Climate Change, Environmental Justice, and River Committee, a copy of which is included as Attachment B and its letter dated October 17, 2022 to the Los Angeles Department of City Planning as to its comments on the MND, a copy of which is included as Attachment C. All of these prior comment letters are incorporated herein by reference. Warren also incorporates by reference all written or oral comments made to the City in opposition to the City's adoption of the proposed Project, the actions recommended in the Agenda, and the adoption of the MND, including those comments of other industry organizations and companies that were submitted in opposition to the proposed Project in connection with the August 30, 2022 Planning Staff Meeting, the September 22, 2022 Planning Commission meeting, the October 6, 2022 Energy, Climate Change, Environmental Justice, and River Committee Meeting and the November 1, 2022 PLUM Committee Meeting.

ATTACHMENT A

Warren
RESOURCES

Green Hill Towers
14131 Midway Rd., Suite 500
Addison, Texas 75001
Office: (214) 393-9688

September 19, 2022

VIA EMAIL: CPC@LACITY.ORG

Los Angeles City Planning Commission
200 N. Spring Street, Room 525
Los Angeles, CA 90012

Re: **Agenda Item #11 - CPC-2022-4864-CA; Council File No. 17-0447**
Warren Comment Letter Opposing Ordinance Amendment and Approval of MND

Dear President Millman and Honorable Commissioners:

This letter provides comments on behalf of Warren E&P, Inc.; Warren Resources of California, Inc.; Warren Resources, Inc.; Warren Management Corp.; and Warren Operating LLC (collectively "Warren") opposing the ordinance amending Sections 12.03, 12.20, 12.23, 12.24, and 13.01 of the Los Angeles Municipal Code (LAMC) to prohibit new oil and gas drilling activities and make existing extraction a noncomforming use in all zones (the "Ordinance Amendment"). While the comment period is still pending for the associated proposed Mitigated Negative Declaration ENV-2022-4865-MND ("MND"), the Commission is being asked to recommend the City Council approve the same and thus, Warren also objects to that action, especially since the Commission does not have the benefit of all comments on that proposed action since they are not due until October 17, 2022. In addition to the comments in this letter, Warren incorporates the comments of other industry organizations and companies that were submitted in connection with the August 30, 2022 Planning Staff Meeting in opposition to the Ordinance Amendment (as attached to the Staff Recommendation Report) and any additional comments that are submitted by other industry organizations and companies in connection with the upcoming September 22, 2022 Planning Commission Meeting.

The Ordinance Amendment Effects an Unconstitutional Taking for Which Just Compensation Must Be Paid & Deprives Warren of Its Vested Rights

At the outset, please understand that the Ordinance Amendment, if adopted in its current form, will put Warren out of business in approximately three years, depriving Warren—and the royalty owners that it serves—of their real property rights. These rights are currently valued in excess of $675MM and the U.S. and California Constitutions require the City to compensate Warren and its mineral owners for these losses. The Ordinance Amendment, however, unlawfully makes no provision for such compensation.

The Ordinance Amendment will result in cessation of Warren's existing production in approximately three years because it prohibits Warren from engaging in the customary operations necessary to maintain production from its existing wells. Warren's only operations and its only mineral rights are located within the City of Los Angeles and new wells are prohibited. As a result, the Ordinance Amendment would unquestionably put Warren out of business after three years, leaving its employees jobless, their families without necessary financial support and its royalty owners without income that they have relied on for decades.

To date, Warren has invested over $400MM to develop its mineral estate in the City of Los Angeles through three well cellars at a consolidated drilling facility (the "Site"). The current LAMC allows for these operations as a *permitted right*. Warren's investment of over $400MM was incurred not merely for its existing production at the Site but also for additional operations on existing wells within the three well cellars, so that production can be maintained over the projected life of the wells, and for the drilling of new wells in the same three cellars. The Ordinance Amendment will affect a zoning change that deprives Warren of engaging in its business at the Site and its business as a whole, subjecting the City's action to heightened scrutiny under the independent judgment standard. (*See e.g., Goat Hill Tavern v. City of Costa Mesa* (1992) 6 Cal.App.4th 1519, 1525.)

Warren and its royalty owners will be deprived of their reasonable investment-backed expectations and of the right to develop the remaining reserves, which are presently valued in excess of $675MM. The Ordinance Amendment thus will result in a taking of Warren's and its royalty owner's real property rights under the U.S. and California Constitutions, thereby subjecting the City to damages for this lost value—a significant liability for the taxpayers of the City of Los Angeles. (*See e.g., Penn Cent. Transp. Co. v New York City* (1978) 438 U.S. 104; *Hansen Brothers Enterprises v. Board of Supervisors* (1996) 12 Cal.4th 533, 553-554 (holding that "absolute prohibition [on mining] . . . practically amounts to a taking of the property").)

Even though it holds mineral rights in other residential areas of the City, Warren limited its operations to the Site and to the three well cellars at the City's specific request. Also at the City's specific request, Warren agreed to give up its right to redrill 560 wells located outside the Site and agreed to a phased process of plugging and abandoning wells in the nearby area in return for the City agreeing that Warren could drill 540 wells at the Site with up to 5 well cellars.[1][2] To date, Warren has plugged and abandoned 41 wells in the surrounding area and has plans to plug and abandon more wells as its business continues to operate in the City.

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[1] Zoning Case ZA 20725-0 (PA1) dated July 20, 2006 and Zoning Case ZA 20725-0 (PA2) dated October 2, 2008 (the "Approvals"), copies of which are not attached hereto due to the 10-page limit for this submission but can be found in the Planning Department records.

[2] Warren was not required under the LAMC relating to the Approvals to give up the redrill rights to 560 wells and conduct the plugging and abandonment of 56 wells in the residential areas <u>outside</u> the Site within a certain time period. Neither were these measures related to the mitigation of environmental impacts. Accordingly, there was no essential nexus and rough proportionality as would be required if the Approvals were interpreted solely as permits under *Nollan v. California Coastal Comm'n,* 483 U.S. 825 (1987) and *Dolan v. City of Tigard,* 512 U.S. 374 (1994). Accordingly, the Approvals constituted a contractual obligation and give rise to a vested property right for that and other reasons. (*See M. J. Brock & Sons, Inc. v. City of Davis,* 401 F.Supp. 354, 361 (1983); *Morrison Homes Corp. v. City of Pleasanton.* 58 Cal.App.3d 724 (1976).) The Ordinance Amendment thus would improperly deny Warren a vested property right in violation of due process of law.

If the Ordinance Amendment is adopted, Warren will not be allowed to complete its project under the terms agreed upon by the City since no new wells will be allowed (221 wells have been drilled to date) and existing production cannot be maintained. Warren, however, has a legally protected and vested property right to utilize the Site for these additional operations. (*See e.g., Avco Community Developers, Inc. v. South Coast Regional Com.* (1976) 17 Cal. 3d 785, 791.)

The *Avco* rule provides that when a property owner has performed substantial work and incurred substantial liabilities in good faith reliance upon an entitlement issued by an agency, the party acquires a vested right to complete the construction of the project. This is particularly true for Warren in that not only did Warren obtain all necessary approvals from the City, but it also gave up its rights to redrill 560 wells in the Wilmington neighborhood outside the Site. Accordingly, Warren must be allowed to complete its project.

Warren's situation is similar to that presented in the case *Goat Hill Tavern v. City of Costa Mesa* (1992) 6 Cal.App.4th 1519, 1530. In that case, as in Warren's, the owner had an underlying right to use the property as a tavern. The owner subsequently obtained a conditional use permit to expand the business. When that permit expired, the City argued that the owner's rights had expired. However, the *Goat Hill Tavern* court held that "once [an approval] has been properly issued the power of a municipality to revoke it is limited . . . Where [an approval] has been properly obtained and in reliance thereon the [grantee] has incurred material expense, he acquires a vested property right to the protection of which he is entitled." (*Goat Hill Tavern*, 6 Cal.App.4th at 1530.)

Similar to *Goat Hill Tavern,* where the tavern owner had an underlying nonconforming use right, Warren also has a right to use the Site as an oil and gas well drilling site by virtue of the City's February 25, 1972 approval of a drilling and production site within the Nonurbanized Oil Drilling District No. 5 in the R4 and M2-1-O zones and by virtue of the Approvals. The *Goat Hill Tavern* court cited to multiple cases in which an agency action would ultimately force the company out of business, which as discussed above is what will happen here with Warren. (*Id.* at 1528-1529.) The court also emphasized that "interference with the right to continue an established business is far more serious than when an agency denies a request for a permit in the first instance." (*Id.* at 1529.) Once a permittee has acquired such a vested right it may be revoked only if the permittee "fails to comply with *reasonable* terms or conditions *expressed* in the permit granted." (*Id.* at 1530 (emphasis added).) Here, the Ordinance Amendment completely revokes Warren's vested rights despite its compliance with terms and conditions expressed in the 1972 approval of the "O" drilling district and in the Approvals, and thus Warren will be deprived of its vested real property rights.

That the City's actions will extinguish Warren's business is readily ascertainable in that Warren must either continuously drill and maintain its wells, or go out of business. The California Supreme Court recognized in *Hansen Brothers Enterprises v. Board of Supervisors* (1996) 12 Cal.4th 533 that unlike other uses that operate within an existing structure or boundary, the use of land for mining and, in this instance, oil and gas drilling, anticipates the need to continuously expand the reach of the extraction activity. Warren must drill new wells and redrill and maintain old wells on the Site to maintain its current business. As stated by the California Supreme Court in *Hansen Brothers,* "this is not the usual case of a business conducted within buildings, nor is the land held merely as a site or location whereon the enterprise can be conducted indefinitely with existing facilities. . . the land itself is a material resource. It constitutes a diminishing asset." *Id.* at 553-554. Accordingly, "the ordinary concept of use must yield to the realities of the business in question and nature of its operations." *Id.* Given Warren's substantial economic investment, Warren's drilling rights are a vested property right and if the City chooses to terminate these rights, Warren would be entitled to compensation under the California and United States constitutions.

Consideration of the Amended Ordinance Now Violates the City's Own Procedural Requirements Such that It Would Be Unlawful to Adopt the Recommended Findings

The relevant City procedures for consideration of the Amended Ordinance are set out at Los Angeles Charter and Administrative Code ("LACAC") Sections 556 and 558. These requirements are further described in the Staff Recommendation Report at the Proposed Findings 1-3 at ps. F-1 to F-6, which Findings the Planning Commission must adopt to recommend adoption of the Amended Ordinance to the City Council.

LACAC Section 558(b)(2) describes the procedures for amending an ordinance. It provides that "[a]fter initiation, the proposed ordinance . . . shall be referred to the City Planning Commission for its report and recommendation regarding the relation of the proposed ordinance . . . to the General Plan and, in the case of proposed zoning regulations, whether adoption of the proposed ordinance . . . will be in conformity with public necessity, convenience, general welfare and good zoning practice."

LACAC Section 556 provides that: "when approving any matter listed in Section 558, the City Planning Commission and the Council shall make findings showing that the action is in substantial conformance with the purposes, intent and provisions of the General Plan."

The Planning Commission's action is not a mere suggestion, but acts to set out how the City Council must proceed in potentially acting on the Ordinance Amendment and the MND. For example, if the Planning Commission recommends approval of the Ordinance Amendment and the MND, the City Council may approve it under a simple majority vote, while if the Planning Commission has recommended against the Ordinance Amendment and the MND, the City Council can only approve the change by a two-thirds vote. (LACAC § 558(b)(3).) Accordingly, the Planning Commission's action on the Amended Ordinance must be in compliance with applicable laws and meet the standards of Sections 556 and 558 of the LACAC.

The Planning Commission Cannot Lawfully Take Action Until It Completes its Review under CEQA

The Planning Commission may not vote to recommend the Amended Ordinance until the City completes the CEQA process. In this situation, the proposed MND was only just circulated to the public on September 15, 2022—four days ago—in conjunction with the issuance of the Staff Recommendation Report. The City states that the public comment period will extend through October 17, 2022, as is required by CEQA. Accordingly, the City has not yet received all comments from the public on the proposed MND and indeed, it would be a denial of due process and violation of CEQA to expect comments in such a short period of time.

Yet at the same time the Planning Commission is being asked to recommend that the City Council find that "after consideration of the whole of the administrative record, including the Mitigated Negative Declaration . . . *and all comments received*, with the imposition of mitigation measures, there is no substantial evidence that the project will have a significant effect on the environment." (Staff Recommendation Report at p. 1-2, and at p. A-8 (emphasis added).)

The Planning Commission is also being asked to adopt Proposed Finding 3, which states that the City has prepared an MND for the project and that "[i]n consideration of the whole administrative record *and all comments received regarding the MND* . . . the City Planning Commission shall recommend the City Council to adopt the MND." (Staff Recommendation Report, Proposed Finding 3 at p. F-6.)

Proposed Finding 2 also clearly requires the completion of the CEQA review. Proposed Finding 2, which the Planning Commission must make pursuant to LACAC Section 556 provides that "[i]n accordance with City Charter Section 558 (b)(2), the proposed ordinance will be in conformance with public necessity, convenience, general welfare, and good zoning practice by advancing the basic core zoning to project citizens' health, safety, and welfare." Impacts to the public's general welfare including its health and safety, however, are evaluated through the CEQA review, which process has not been completed and the comment period is still pending.

Accordingly, pursuant to LACAC Sections 556 and 558 and Proposed Finding 2 and 3, the Planning Commission must complete the CEQA process, including completion of the public comment period, prior to taking action to recommend adoption of the MND and adoption of the Amended Ordinance by the City Council.

Even without these explicit requirements, the proposed action would violate CEQA. Amendments to ordinances are clearly a project under CEQA. The completion of the CEQA process, including the required comment period and the consideration of these comments, is necessary as to two fundamental purposes of CEQA, informed decision making *by the agency* and informed public participation. The case law is clear that the failure to satisfy these requirements is prejudicial error. (*County of Amador v. El Dorado County Water Agency* (1999) 76 Cal.App.4th 931, 946.)

The California Supreme Court has explicitly rejected what the Planning Commission is being asked to do—take an action prior to the completion of CEQA review. In particular, in *Laurel Heights Improvement Assn. v. Regents of University of California* (1988) 47 Cal.3d 388, 394 the Supreme Court stated that:

> A fundamental purpose of [a CEQA document] is to provide decision makers with information they can use in deciding whether to approve a proposed project, not to inform them of the environmental effects of projects that they have already approved. If post approval environmental review were allowed, [CEQA documents] would likely become nothing more than post hoc rationalizations to support action already taken. We have expressly condemned this.

Accordingly, under not only its own requirements under CACAC Sections 556 and 558 and under the language proposed in the recommended actions and Proposed Findings, but also under basic CEQA law, the Planning Commission cannot act on the recommendation until the CEQA process is complete. Otherwise, the Planning Commission will deprive the public of the right to participate in the process and prevent itself from engaging in informed decision making.

A Brief Review of the MND Indicates That the City Must Prepare an EIR for the Proposed Project

A brief review of the MND (it was only published four days ago) indicates that the Planning Department has understated the impacts that will result from this project. It is clear that, ultimately, the City will be required to prepare an EIR.

The MND's analysis of greenhouse gas emissions ("GHGs") is clearly deficient because it only analyzes the direct impacts related to curtailing oil and gas production in the City. It does not analyze any indirect impacts related to the termination of oil and gas production, which it is required to do under CEQA. (CEQA Guidelines Section 15064(d).) For example, the MND does not discuss that the termination of oil and gas extraction and production activities will result in additional imports of oil to the State and region, and that importation will result in additional GHGs through, for example, additional tanker emissions.

The MND also is required to discuss the consistency of the Ordinance Amendment with City land use policies. As they did with the Proposed Findings, the MND fails to address multiple policies that support the extraction and production of oil within the City (as discussed above).

Further, the MND glosses over the impacts to mineral resources in determining that the impacts related to the Ordinance Amendment are insignificant. As described above, the MND omits critical information from the General Plan related to the encouragement of extraction to reduce dependency on oil imports. The MND's remarks that the City "does not consider petroleum to be a mineral resource of local importance" is thus not supported by the City's own General Plan. Moreover, the CEQA Guidelines require the City to evaluate "the loss of availability of a known mineral resource that would be of value to the region and the residents of the state" not just the City. Accordingly, the analysis is flawed in that it addresses only impacts to the City, not the State as a whole.

The MND's conclusion that oil produced in the area "represents a small amount of the available Statewide resource" is also contradicted by readily available public information. For example, a report by the US Geological Service dated February 2013 describes the Los Angeles Basin, which is partly encompassed by the City, as containing "one of the highest concentrations of crude oil in the world. Sixty-eight oil fields have been named . . . including 10 accumulations that each contain more than 1 billion barrels of oil. One of these, the Wilmington-Belmont, is the fourth largest oil field in the United States." (USGS Fact Sheet 2012-3120.) Accordingly, based on this expert evidence it is undeniable, that the proposed ordinance will have a significant impact on the availability of mineral resources. Based on this information alone, the City is required to develop an EIR. CEQA requires that where there is substantial evidence supporting a fair argument that the project could have a significant non-mitigable effect the City must prepare an EIR. (CEQA Guidelines Section 15064(f)(1).) Even where there is "disagreement among expert opinion supported by the facts over the significance of an effect on the environment, the Lead Agency shall treat the effect as significant and shall prepare an EIR." (CEQA Guidelines Section 15064(g).)

The City's General Plan Review For Conformity is Incomplete and Thus Unlawful

At noted above, CACAC Section 556 provides that the Planning Commission must find that proposed ordinance is in conformity with the General Plan. Such consistency is required by law. (*See e.g., City of Los Angeles v. State of California* (1982) 138 Cal.App.3d 526, 532.) This consistency is also required for charter cities pursuant to Government Code Section 65860. As discussed below, the ***Ordinance Amendment is not consistent with the City's General Plan.***

The Staff Recommendation Report at Proposed Finding 1 leaves out critical elements in the General Plan in concluding that the Ordinance Amendment is in conformance with the purposes and intent of the General Plan. For example, in discussing the Conservation Element of the General Plan, Proposed Finding 1 sets out three policies. These policies generally describe a need for encouraging energy conservation, supporting the ban on offshore drilling and protecting neighborhoods from potential accidents and subsidence associated with drilling and production.

However, listed directly above these policies, and not stated in Finding 1, is the "Objective" that these policies support. In particular, the objective is to: "conserve petroleum resources and *enable appropriate, environmentally sensitive extraction* . . . so as to protect the petroleum resources for the use of future generations and to reduce the city's dependency on imported petroleum and petroleum products." (Emphasis added.) Accordingly, these policies may only be read in the context of allowing continued extraction. The fact that the Amended Ordinance would *ban extraction* rather than *enable extraction* clearly means that it is inconsistent with the General Plan.

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Similarly, a brief review of the Land Use Element – Wilmington Harbor City Community Plan likewise indicates that the Amended Ordinance is inconsistent with the Wilmington Harbor City Community Plan. For example, Policies 3-5.1 and 3.5.3 clearly contemplate the continuance of extraction activities. Policy 3-5.4 provides for the consolidation of oil extraction operations to increase compatibility between oil activities and other land uses. Accordingly, nothing in these policies is consistent with a total ban on oil production like that proposed in the Ordinance Amendment. Finding 1 also does not discuss Objective 3-5, which the policies are drafted to support and which provides that the objective of the policies is "[t]o ensure the public health, safety and welfare *while providing for reasonable utilization* of the area's oil and gas resources." (Emphasis added.) The Staff Recommendation Report also fails to note Policy 3-4.6, which encourages the *consolidation* of oil extraction activities rather than its *elimination.*

Accordingly, not only is the Ordinance Amendment inconsistent with the General Plan and thus unlawful, but the Staff Recommendation Report omits critical information necessary for Planning Commission and public review of the Ordinance Amendment.

The Ordinance Amendment is Unconstitutionally Vague and Ambiguous

The Ordinance Amendment provides that "[no] existing well . . . shall be "*maintained*, drilled, re-drilled, or deepened, except to prevent or respond to a threat to public health, safety, or the environment, as determined by the Zoning Administrator." (Emphasis added.) The Ordinance Amendment, however, provides no definition of the word "maintained" and it is thus unconstitutionally vague and ambiguous and violates the due process clause of the U.S. Constitution. The Staff Recommendation Report acknowledges that this is a problem and defers to a "Zoning Administrator's Interpretation" that has not yet been published as to what this term means. (Staff Recommendation Report, P.3 ("Separately from this Ordinance, DCP's Office of Zoning Administration is preparing a Zoning Administrator's Interpretation on the types of oil-related activities that constitute maintenance . . . Once final, this guidance would immediately apply to all oil drilling activities. It would further clarify the types of maintenance activities prohibited under the Ordinance, with limited exceptions to prevent or respond to threats to public health, safety, or the environment.")

Due process requires fair notice and an opportunity to be heard. In turn, the most basic due process concepts require that legally enforceable ordinances be defined with sufficient clarity such that those subjected to the laws understand what is permitted and what is prohibited, and such that the laws are not susceptible to arbitrary or discriminatory enforcement. (*Genis v. Bell (C.D. Cal. July 2, 2013) 2013 U.S. Dist. LEXIS 93353,* *14-15; *see also Castro v. Terhune*, 712 F.3d 1304, 1307 (9th Cir. 2013).) Here, the failure to unambiguously explain what is meant by the word "maintained" in the Ordinance Amendment itself would mean that Warren and others similarly situated would not know when, if at all, it is violating the Ordinance Amendment. As written without any definition, Warren is deprived of advance notice and opportunity to object to the meaning of the term "maintained" since it is left to later interpretation by the Zoning Administrator.

The 20-Year Amortization Period in the Ordinance Amendment is Unlawful

The Ordinance Amendment unlawfully imposes a 20-year amortization period for existing operations without any factual evidence to support that 20 years is a "reasonable amortization period commensurate with the investment involved," as required by law. (*Metromedia, Inc. v. San Diego* (1980) 26 Cal.3d 848, 882.) The City Council directed the Planning Department to commission a study to be performed as to an appropriate amortization period and that work has not yet even commenced, let alone been completed. It thus is premature and unlawful for the Planning Commission to proceed with taking action on an amortization period when there is no study—and no evidence—to support such a period for Warren or other operators within the City.

Moreover, there is no law in California to support the use of amortization periods to eliminate a diminishing asset like mineral rights. While amortization may be appropriate under certain factual situations involving movable property like billboards or liquor stores, since those uses can be moved to other locations, the development of mineral rights is immovable and, as discussed above, protected under the diminishing asset doctrine. There is no way to equitably amortize Warren's real property rights and its investments therein other than to allow Warren to produce until the commercially recoverable resources are depleted.

There is No Evidence to Support that Warren's Operations Result in Negative Health Effects

Warren not only complies with California's stringent environmental regulations, but it also agreed with the City to use electric sources for its operations except for two combustion sources which produce minimal emissions and are not a significant impact for the City. The Staff Recommendation Report contains no specific evidence as to Warren's operations or its emissions and also ignores the City's prior report that failed to support any negative health impacts from oil and gas operations within the City.

In 2019, the City of Los Angeles Office of Petroleum and Natural Gas Administration and Safety conducted an exhaustive review of government reports and studies and concluded that:

> There is a lack of empirical evidence correlating oil and gas operations within the City of Los Angeles to widespread negative health impacts. The lack of evidence of public health impacts from oil and natural gas operations has been demonstrated locally in multiple studies by the Los Angeles County Department of Public Health, the Los Angeles County Oil & Gas Strike Team, the South Coast Air Quality Management District and the comprehensive Kern County Environmental Impact Report and Health Risk Assessment.

The City's position now is contrary to that prior report and not supported by the evidence. Warren's equipment and operations do not emit significant quantities of air pollutants and do not pose a significant health risk to the community residents or the public. Warren participates in annual emissions reporting to the SCAQMD, which includes mandatory reporting of air pollutants regulated by the Clean Air Act. Warren facility's actual emissions are low and based on these reported emissions the facility has never been required to obtain a federal operating air permit as it remains below major source thresholds for all pollutants. Further, low emissions of regulated pollutants is evidenced by the fact that Warren does not participate in the SCAQMD's RECLAIM program for large sources of oxides of nitrogen (NOx) and sulfur (SOx). Lastly, as a minor stationary source located in a heavily industrialized area of Wilmington, Warren has not permitted or installed new equipment or modified existing equipment in over 6 years.

In addition to regulated pollutants, Warren has consistently reported low emissions of air contaminants. The facility routinely reports a detailed air toxics emissions inventory to the SCAQMD yet has never been required by the SCAQMD to prepare a Health Risk Assessment (HRA) because of low emissions. For example, Warren's reported emission of air pollutants and associated health risk impacts are on par with that of neighborhood gas station that operates fuel dispensing equipment, storage tanks, and vehicular traffic from customers and mobile tankers.

Warren is in compliance with all regional, state, and federal rules and regulations and has obtained the appropriate air quality permits for all operating equipment. Restricting maintenance, testing, and repair of the existing equipment would not represent an emission reduction or result in any improved air quality for the area or the region.

Furthermore, and in violation of the Equal Protection Clause as applied through the Fourteenth Amendment to the U.S. Constitution, the City is unlawfully discriminating against one industry by prohibiting its operations within the City without taking similar actions against other industries or uses that provide similar or even more emissions than the oil and gas industry.

No Action Should Be Taken on the Ordinance Amendment and the MND

Warren respectfully requests that the Planning Commission do everything within its power to avoid what will prove to be an expensive mistake and we urge you ***not*** to take action on Agenda Item No. 11. The Ordinance Amendment will not result in the professed health benefits from shutting down Warren's operations and, instead, will subject the City to significant liability.

It is even premature for the Planning Commission to consider the draft MND and the Ordinance Amendment at this time. Indeed, the comment period has just began to run on the draft MND so the rush to take action should heed to the Commission's obligations to comply with the law and the City's ordinances.

Please understand that if the Planning Commission recommends approval, Warren will take all actions required to protect its rights, including seeking recovery from the City of in excess of $675MM in damages for putting Warren out of business, along with recovery of Warren's legal expenses under Code of Civil Procedure Sections 1021.5 and 1036. The City will be forced to incur substantial legal fees for its own counsel and ultimately Warren's counsel too, all the while losing significant revenue from property taxes on future oil and gas operations without any change in health impacts from closing Warren's doors. Warren reserves all of its rights to pursue every available remedy if the Planning Commission proceeds to recommend approval of the Ordinance Amendment and the draft MND to the City Council.

Sincerely,

WARREN RESOURCES, INC.

James A. Watt
President and Chief Executive Officer

ATTACHMENT B

Warren RESOURCES

October 5, 2022

VIA ONLINE PUBLIC COMMENT FORM: https://cityclerk.lacity.org/publiccomment/

Los Angeles City Council
Energy, Climate Change, Environmental Justice, and River Committee
200 N. Spring Street
Los Angeles, CA 90012

Re: **Agenda Item #2; Council File No. 17-0447-S2**
Warren Comment Letter Opposing Ordinance Amendment and Approval of MND

Dear Chairperson O'Farrell and Councilmembers Koretz, Cedillo, De Leon, and Krekorian:

This letter provides comments on behalf of Warren E&P, Inc.; Warren Resources of California, Inc.; Warren Resources, Inc.; Warren Management Corp.; and Warren Operating LLC (collectively "Warren") opposing the ordinance amending Sections 12.03, 12.20, 12.23, 12.24, and 13.01 of the Los Angeles Municipal Code (LAMC) to prohibit new oil and gas drilling activities and make existing extraction a noncomforming use in all zones (the "Ordinance Amendment"). The comment period is still pending for the associated proposed Mitigated Negative Declaration ENV-2022-4865-MND ("MND"), and thus the Committee is being asked to consider the MND, and the Planning Commission has already recommended that the City Council approve the same, when all comments have not yet been submitted. Warren thus also objects to the process since the Committee does not, and the Planning Commission did not, have the benefit of all comments on the MND, which are not due until October 17, 2022. In addition to the comments in this letter, Warren incorporates its prior comments to the City Planning Commission, the comments of other industry organizations and companies that were submitted in connection with the August 30, 2022 Planning Staff Meeting and the September 22, 2022 Planning Commission meeting in opposition to the Ordinance Amendment, and any additional comments that are submitted by other industry organizations and companies in opposition to the Ordinance Amendment.

The Ordinance Amendment Effects an Unconstitutional Taking for Which Just Compensation Must Be Paid & Deprives Warren of Its Vested Rights

At the outset, please understand that the Ordinance Amendment, if adopted in its current form, will put Warren out of business in approximately three years, depriving Warren—and the royalty owners that it serves—of their real property rights. These rights are currently valued in excess of $675MM, and the U.S. and California Constitutions require the City to compensate Warren and its mineral owners for these losses. The Ordinance Amendment, however, unlawfully makes no provision for such compensation.

The Ordinance Amendment will result in cessation of Warren's existing production in approximately three years because it prohibits Warren from engaging in the customary operations necessary to maintain production from its existing wells. Warren's only operations and its only mineral rights are located within the City of Los Angeles and new wells are prohibited. As a result, the Ordinance Amendment would unquestionably put Warren out of business after three years, leaving its employees jobless, their families without necessary financial support and its royalty owners without income that they have relied on for decades.

To date, Warren has invested over $400MM to develop its mineral estate in the City of Los Angeles through three well cellars at a consolidated drilling facility (the "Site"). The current LAMC allows for these operations as a *permitted right*. Warren's investment of over $400MM was incurred not merely for its existing production at the Site but also for additional operations on existing wells within the three well cellars, so that production can be maintained over the projected life of the wells, and for the drilling of new wells in the same three cellars. The Ordinance Amendment will affect a zoning change that deprives Warren of engaging in its business at the Site and its business as a whole, subjecting the City's action to heightened scrutiny under the independent judgment standard. (*See e.g., Goat Hill Tavern v. City of Costa Mesa* (1992) 6 Cal.App.4th 1519, 1525.)

Warren and its royalty owners will be deprived of their reasonable investment-backed expectations and of the right to develop the remaining reserves, which are presently valued in excess of $675MM. The Ordinance Amendment thus will result in a taking of Warren's and its royalty owner's real property rights under the U.S. and California Constitutions, thereby subjecting the City to damages for this lost value—a significant liability for the taxpayers of the City of Los Angeles. (*See e.g., Penn Cent. Transp. Co. v New York City* (1978) 438 U.S. 104; *Hansen Brothers Enterprises v. Board of Supervisors* (1996) 12 Cal.4th 533, 553-554 (holding that "absolute prohibition [on mining] . . . practically amounts to a taking of the property").)

Even though it holds mineral rights in other residential areas of the City, Warren limited its operations to the Site and to the three well cellars at the City's specific request. Also at the City's specific request, Warren agreed to give up its right to redrill 560 wells located outside the Site and agreed to a phased process of plugging and abandoning wells in the nearby area in return for the City agreeing that Warren could drill 540 wells at the Site with up to 5 well cellars.[1][2] To date, Warren has plugged and abandoned 41 wells in the surrounding area and has plans to plug and abandon more wells as its business continues to operate in the City.

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[1] Zoning Case ZA 20725-0 (PA1) dated July 20, 2006 and Zoning Case ZA 20725-0 (PA2) dated October 2, 2008 (the "Approvals").

[2] Warren was not required under the LAMC relating to the Approvals to give up the redrill rights to 560 wells and conduct the plugging and abandonment of 56 wells in the residential areas <u>outside</u> the Site within a certain time period. Neither were these measures related to the mitigation of environmental impacts. Accordingly, there was no essential nexus and rough proportionality as would be required if the Approvals were interpreted solely as permits under *Nollan v. California Coastal Comm'n,* 483 U.S. 825 (1987) and *Dolan v. City of Tigard,* 512 U.S. 374 (1994). Accordingly, the Approvals constituted a contractual obligation and give rise to a vested property right for that and other reasons. (*See M. J. Brock & Sons, Inc. v. City of Davis,* 401 F.Supp. 354, 361 (1983); *Morrison Homes Corp. v. City of Pleasanton*. 58 Cal.App.3d 724 (1976).) The Ordinance Amendment thus would improperly deny Warren a vested property right in violation of due process of law.

If the Ordinance Amendment is adopted, Warren will not be allowed to complete its project under the terms agreed upon by the City since no new wells will be allowed (221 wells have been drilled to date) and existing production cannot be maintained. Warren, however, has a legally protected and vested property right to utilize the Site for these additional operations. (*See e.g., Avco Community Developers, Inc. v. South Coast Regional Com.* (1976) 17 Cal. 3d 785, 791.)

The *Avco* rule provides that when a property owner has performed substantial work and incurred substantial liabilities in good faith reliance upon an entitlement issued by an agency, the party acquires a vested right to complete the construction of the project. This is particularly true for Warren in that not only did Warren obtain all necessary approvals from the City, but it also gave up its rights to redrill 560 wells in the Wilmington neighborhood outside the Site. Accordingly, Warren must be allowed to complete its project.

Warren's situation is similar to that presented in the case *Goat Hill Tavern v. City of Costa Mesa* (1992) 6 Cal.App.4th 1519, 1530. In that case, as in Warren's, the owner had an underlying right to use the property as a tavern. The owner subsequently obtained a conditional use permit to expand the business. When that permit expired, the City argued that the owner's rights had expired. However, the *Goat Hill Tavern* court held that "once [an approval] has been properly issued the power of a municipality to revoke it is limited . . . Where [an approval] has been properly obtained and in reliance thereon the [grantee] has incurred material expense, he acquires a vested property right to the protection of which he is entitled." (*Goat Hill Tavern*, 6 Cal.App.4th at 1530.)

Similar to *Goat Hill Tavern,* where the tavern owner had an underlying nonconforming use right, Warren also has a right to use the Site as an oil and gas well drilling site by virtue of the City's February 25, 1972 approval of a drilling and production site within the Nonurbanized Oil Drilling District No. 5 in the R4 and M2-1-O zones and by virtue of the Approvals. The *Goat Hill Tavern* court cited to multiple cases in which an agency action would ultimately force the company out of business, which as discussed above is what will happen here with Warren. (*Id.* at 1528-1529.) The court also emphasized that "interference with the right to continue an established business is far more serious than when an agency denies a request for a permit in the first instance." (*Id.* at 1529.) Once a permittee has acquired such a vested right it may be revoked only if the permittee "fails to comply with *reasonable* terms or conditions *expressed* in the permit granted." (*Id.* at 1530 (emphasis added).) Here, the Ordinance Amendment completely revokes Warren's vested rights despite its compliance with terms and conditions expressed in the 1972 approval of the "O" drilling district and in the Approvals, and thus Warren will be deprived of its vested real property rights.

That the City's actions will extinguish Warren's business is readily ascertainable in that Warren must either continuously drill and maintain its wells, or go out of business. The California Supreme Court recognized in *Hansen Brothers Enterprises v. Board of Supervisors* (1996) 12 Cal.4th 533 that unlike other uses that operate within an existing structure or boundary, the use of land for mining and, in this instance, oil and gas drilling, anticipates the need to continuously expand the reach of the extraction activity. Warren must drill new wells and redrill and maintain old wells on the Site to maintain its current business. As stated by the California Supreme Court in *Hansen Brothers,* "this is not the usual case of a business conducted within buildings, nor is the land held merely as a site or location whereon the enterprise can be conducted indefinitely with existing facilities. . . the land itself is a material resource. It constitutes a diminishing asset." *Id.* at 553-554. Accordingly, "the ordinary concept of use must yield to the realities of the business in question and nature of its operations." *Id.* Given Warren's substantial economic investment, Warren's drilling rights are a vested property right and if the City chooses to terminate these rights, Warren would be entitled to compensation under the California and United States constitutions.

The Planning Commission Unlawfully Took Action Prior to Completing its Review under CEQA

The Planning Commission unlawfully voted to recommend the Amended Ordinance prior to the City completing the CEQA process. In this situation, the proposed MND was only just circulated to the public on September 15, 2022, in conjunction with the issuance of the Staff Recommendation Report. The City states that the public comment period will extend through October 17, 2022, as is required by CEQA. Accordingly, the City has not yet received all comments from the public on the proposed MND and indeed, it would be a denial of due process and violation of CEQA to expect comments in such a short period of time. Impacts to the public's general welfare including its health and safety are evaluated through the CEQA review, which process has not been completed and the comment period is still pending. Accordingly, the Planning Commission was required to complete the CEQA process, including completion of the public comment period, prior to taking action to recommend adoption of the MND and adoption of the Amended Ordinance by the City Council.

Even without these explicit requirements, the proposed action would violate CEQA. Amendments to ordinances are clearly a project under CEQA. The completion of the CEQA process, including the required comment period and the consideration of these comments, is necessary as to two fundamental purposes of CEQA, informed decision making *by the agency* and informed public participation. The case law is clear that the failure to satisfy these requirements is prejudicial error. (*County of Amador v. El Dorado County Water Agency* (1999) 76 Cal.App.4th 931, 946.)

The California Supreme Court has explicitly rejected what the Planning Commission did here—took an action prior to the completion of the CEQA review process. In particular, in *Laurel Heights Improvement Assn. v. Regents of University of California* (1988) 47 Cal.3d 388, 394 the Supreme Court stated that:

> A fundamental purpose of [a CEQA document] is to provide decision makers with information they can use in deciding whether to approve a proposed project, not to inform them of the environmental effects of projects that they have already approved. If post approval environmental review were allowed, [CEQA documents] would likely become nothing more than post hoc rationalizations to support action already taken. We have expressly condemned this.

Accordingly, under not only its own requirements, but also under basic CEQA law, the Planning Commission unlawfully made a recommendation prior to completion of the CEQA process, thereby depriving the public of the right to participate in the process and preventing itself and your Committee from engaging in informed decision making.

A Brief Review of the MND Indicates That the City Must Prepare an EIR for the Proposed Project

A brief review of the MND[3] indicates that the Planning Department has understated the impacts that will result from this project. It is clear that, ultimately, the City will be required to prepare an EIR.

The MND's analysis of greenhouse gas emissions ("GHGs") is clearly deficient because it only analyzes the direct impacts related to curtailing oil and gas production in the City. It does not analyze any indirect impacts related to the termination of oil and gas production, which it is required to do under CEQA. (CEQA Guidelines Section 15064(d).) For example, the MND does not discuss that the termination of oil and gas extraction and production activities will result in additional imports of oil to the State and region, and that importation will result in additional GHGs through, for example, additional tanker emissions.

The MND severely underestimates the potential air quality and health risk impacts from the condensed schedule to plug and abandon wells and uses incorrect assumptions in calculating those impacts. For example, the horsepower rating of the main equipment item (the workover rig) is grossly underestimated. The MND's technical report shows that 33 bhp was used for the workover rig's power rating, whereas the normal range for a self-propelled mobile tractor-based workover rig is 450 bhp to 1,000 bhp. Warren will provide expert submissions prior to the October 17 comment deadline with more details on these issues. This analysis indicates that the ordinance will result in a significant impact to air quality.

The MND also is required to discuss the consistency of the Ordinance Amendment with City land use policies. The MND fails to address multiple policies that support the extraction and production of oil within the City (as discussed below).

Further, the MND glosses over the impacts to mineral resources in determining that the impacts related to the Ordinance Amendment are insignificant. As described above, the MND omits critical information from the General Plan related to the encouragement of extraction to reduce dependency on oil imports. The MND's remarks that the City "does not consider petroleum to be a mineral resource of local importance" is thus not supported by the City's own General Plan. Moreover, the CEQA Guidelines require the City to evaluate "the loss of availability of a known mineral resource that would be of value to the region and the residents of the state" not just the City. Accordingly, the analysis is flawed in that it addresses only impacts to the City, not the State as a whole.

The MND's conclusion that oil produced in the area "represents a small amount of the available Statewide resource" is also contradicted by readily available public information. For example, a report by the US Geological Service dated February 2013 describes the Los Angeles Basin, which is partly encompassed by the City, as containing "one of the highest concentrations of crude oil in the world. Sixty-eight oil fields have been named . . . including 10 accumulations that each contain more than 1 billion barrels of oil. One of these, the Wilmington-Belmont, is the fourth largest oil field in the United States." (USGS Fact Sheet 2012-3120.) Accordingly, based on this expert evidence it is undeniable, that the proposed

[3] Warren will be submitting more fulsome comments to the MND prior to the October 17, 2022 deadline.

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At discussed in more detail below, Los Angeles Charter and Administrative Code Section 556 provides that the Planning Commission must find that proposed ordinance is in conformity with the General Plan. Such consistency is required by law. (*See e.g., City of Los Angeles v. State of California* (1982) 138 Cal.App.3d 526, 532.) This consistency is also required for charter cities pursuant to Government Code Section 65860. As discussed below, the ***Ordinance Amendment is not consistent with the City's General Plan.***

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Moreover, there is no law in California to support the use of amortization periods to eliminate a diminishing asset like mineral rights. While amortization may be appropriate under certain factual situations involving movable property like billboards or liquor stores, since those uses can be moved to other locations, the development of mineral rights is immovable and, as discussed above, protected under the diminishing asset doctrine. There is no way to equitably amortize Warren's real property rights and its investments therein other than to allow Warren to produce until the commercially recoverable resources are depleted.

There is No Evidence to Support that Warren's Operations Result in Negative Health Effects

Warren not only complies with California's stringent environmental regulations, but it also agreed with the City to use electric sources for its operations except for two combustion sources which produce minimal emissions and are not a significant impact for the City. The Staff Recommendation Report contains no specific evidence as to Warren's operations or its emissions and also ignores the City's prior report that failed to support any negative health impacts from oil and gas operations within the City.

In 2019, the City of Los Angeles Office of Petroleum and Natural Gas Administration and Safety conducted an exhaustive review of government reports and studies and concluded that:

> There is a lack of empirical evidence correlating oil and gas operations within the City of Los Angeles to widespread negative health impacts. The lack of evidence of public health impacts from oil and natural gas operations has been demonstrated locally in multiple studies by the Los Angeles County Department of Public Health, the Los Angeles County Oil & Gas Strike Team, the South Coast Air Quality Management District and the comprehensive Kern County Environmental Impact Report and Health Risk Assessment.[4]

The City's position now is contrary to that prior report and not supported by the evidence. Warren's equipment and operations do not emit significant quantities of air pollutants and do not pose a significant health risk to the community residents or the public. Warren participates in annual emissions reporting to the SCAQMD, which includes mandatory reporting of air pollutants regulated by the Clean Air Act. Warren facility's actual emissions are low and based on these reported emissions the facility has never been required to obtain a federal operating air permit as it remains below major source thresholds for all pollutants. Further, low emissions of regulated pollutants are evidenced by the fact that Warren does not participate in the SCAQMD's RECLAIM program for large sources of oxides of nitrogen (NOx) and

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[4] https://clkrep.lacity.org/onlinedocs/2017/17-0447_rpt_BPW_07-29-2019.pdf at page 145.

sulfur (SOx). Lastly, as a minor stationary source located in a heavily industrialized area of Wilmington, Warren has not permitted or installed new equipment or modified existing equipment in over 6 years.

In addition to regulated pollutants, Warren has consistently reported low emissions of air contaminants. The facility routinely reports emissions to the SCAQMD yet has never been required by the SCAQMD to prepare a Health Risk Assessment (HRA) because of low emissions. For example, Warren's reported emission of air pollutants and associated health risk impacts are on par with that of a supermarket with a fast-food restaurant or of a fast-food restaurant with a drive through.

Warren is in compliance with all regional, state, and federal rules and regulations and has obtained the appropriate air quality permits for all operating equipment. Restricting maintenance, testing, and repair of the existing equipment would not represent an emission reduction or result in any improved air quality for the area or the region.

Furthermore, and in violation of the Equal Protection Clause as applied through the Fourteenth Amendment to the U.S. Constitution, the City is unlawfully discriminating against one industry by prohibiting its operations within the City without taking similar actions against other industries or uses that provide similar or even more emissions than the oil and gas industry.

Consideration of the Amended Ordinance Now Violates the City's Own Procedural Requirements

The relevant City procedures for consideration of the Amended Ordinance are set out at Los Angeles Charter and Administrative Code ("LACAC") Sections 556 and 558. These requirements are further described in the Planning Staff Recommendation Report at Proposed Findings 1-3, at pages F-1 to F-6, which Findings the Planning Commission should have adopted to recommend adoption of the Amended Ordinance to the City Council.

LACAC Section 558(b)(2) describes the procedures for amending an ordinance. It provides that "[a]fter initiation, the proposed ordinance . . . shall be referred to the City Planning Commission for its report and recommendation regarding the relation of the proposed ordinance . . . to the General Plan and, in the case of proposed zoning regulations, whether adoption of the proposed ordinance . . . will be in conformity with public necessity, convenience, general welfare and good zoning practice."

LACAC Section 556 provides that: "when approving any matter listed in Section 558, the City Planning Commission and the Council shall make findings showing that the action is in substantial conformance with the purposes, intent and provisions of the General Plan."

The Planning Commission's action is not a mere suggestion, but acts to set out how the City Council must proceed in potentially acting on the Ordinance Amendment and the MND. For example, since the Planning Commission recommended approval of the Ordinance Amendment and the MND, the City Council may approve it under a simple majority vote, whereas if the Planning Commission had recommended against the Ordinance Amendment and the MND, the City Council could only approve the change by a two-thirds vote. (LACAC § 558(b)(3).) Accordingly, the Planning Commission's action on the Amended Ordinance were required to be in compliance with applicable laws and meet the standards of Sections 556 and 558 of the LACAC, but it failed to do so.

No Action Should Be Taken on the Ordinance Amendment and the MND

Warren respectfully requests that the Committee do everything within its power to avoid what will prove to be an expensive mistake and we urge you ***not*** to move forward with the Ordinance Amendment. The Ordinance Amendment will not result in the professed health benefits from shutting down Warren's operations and, instead, will subject the City to significant liability.

It is premature to consider the draft MND and the Ordinance Amendment at this time. Indeed, the comment period has not yet run on the draft MND so the rush to proceed should heed to the City's obligations to comply with the law and the City's ordinances.

Please understand that if the Ordinance Amendment is approved and the MND adopted, Warren will take all actions required to protect its rights, including seeking recovery from the City of in excess of $675MM in damages for putting Warren out of business, along with recovery of Warren's legal expenses under Code of Civil Procedure Sections 1021.5 and 1036. The City will be forced to incur substantial legal fees for its own counsel and ultimately Warren's counsel too, all the while losing significant revenue from property taxes on future oil and gas operations without any change in health impacts from closing Warren's doors. Warren reserves all of its rights to pursue every available remedy if the City approves the Ordinance Amendment and adopts the draft MND.

Sincerely,

WARREN RESOURCES, INC.

/s/ James A. Watt
President & Chief Executive Officer

ATTACHMENT C

DAY ▪ CARTER ▪ MURPHY LLP

3620 American River Dr., Suite 205
Sacramento, CA 95864
T: 916.570.2500

daycartermurphy.com

Thomas A. Henry
thenry@daycartermurphy.com

October 17, 2022

VIA EMAIL ONLY
[PLANNING.OILDRILLING@LACITY.ORG]
[CPC@LACITY.ORG]

Jennifer Torres
City of Los Angeles Department of City Planning
200 North Spring Street, Room 701
Los Angeles, CA 90012

Re: *Comments on Proposed Mitigated Negative Declaration, ENV-2022-4865-MND Regarding Proposed Amendments to the City's Oil and Gas Ordinance*

Dear City Council, Planning Commission and Planning Director:

This firm represents Warren E&P, Inc.; Warren Resources of California, Inc.; Warren Resources, Inc.; Warren Management Corp.; and Warren Operating LLC (collectively "Warren").[1] On behalf of Warren, we are providing these comments on the draft mitigated negative declaration described as ENV-2022-4865-MND (MND), prepared by the City of Los Angeles ("City") for consideration of a draft ordinance to amend sections of the Oil and Gas Drilling Ordinance ("Proposed Ordinance" or "Project").

The City may not lawfully adopt the MND because of numerous deficiencies in the document. As described below, the City failed to analyze the whole of the project in that it states that future parts of the project will be drafted and considered at a future date.

The MND also is deficient in that there is substantial evidence that the Project may have a significant effect on the environment and accordingly an environmental impact report (EIR) must be

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[1] Warren operates drilling and production sites within the City and would be detrimentally affected by the Project. It has a beneficial interest that would be adversely affected by the environmental impacts associated with the Project, and the Project will otherwise have a direct, substantial effect on Warren and its operations. Further, Warren makes these comments on behalf of the public interest, which interest would suffer if the City were not compelled to perform its duties under CEQA.

prepared by the City to evaluate the Project. We further note that the City has failed to proceed in a manner required by law, in part, because it has failed to comply with CEQA's analysis and information disclosure requirements, therefore preventing significant information from being presented to the City decision makers and the public, which failure constitutes a prejudicial abuse of discretion.

A. The MND Fails to Evaluate the Whole of the Project By Providing That Future, Foreseeable Actions, Including Plugging, Abandonment, Remediation, Proper Amortization and the Meaning of "Maintenance," All Will Be Reviewed and Adopted at a Later Date.

CEQA requires the consideration, analysis and disclosure of all potentially significant environmental impacts of a proposed "project." CEQA Guidelines [Cal. Code Regs., titl. 14, § 15000 et seq.], § 15060. "Project" is defined as the ***entire*** activity before the agency, the "***whole of the action***, which has a potential for resulting in either a direct physical change in the environment, or a reasonably foreseeable indirect physical change in the environment." CEQA Guidelines, § 15378 (emphasis added). "Accordingly, CEQA forbids piecemeal review of the significant environmental impacts of a project. Agencies cannot allow environmental considerations to become submerged by chopping a large project into many little ones." *Banning Ranch Conservancy v. City of Newport Beach* (2012) 211 Cal.App.4th 1209, 1222 (internal citations omitted).

As the City blatantly concedes, the entire activity before the City is the phasing-out of oil operations within its City limits, but the MND illegally only analyzes a portion of that project:

- "There are many other follow up actions that the City will undertake to ensure the safe phase-out of oil operations citywide and to address the issues that have been raised regarding oil. In addition to this proposed Ordinance, OPNGAS has been tasked with preparing an amortization study to examine the length of time needed for operators their capital investments in oil drilling operations to determine whether individual oil drilling operations must be terminated sooner than the 20 years currently prescribed in the LAMC. City Council has also instructed OPNGAS, in collaboration with DCP and the Los Angeles Fire Department (LAFD), to develop policies for the timely abandonment and remediation of existing well sites." Staff Report, A-2 to A-3.

- "Although the Ordinance does not directly regulate remediation outside of [one] mitigation measure, it represents the first step taken by the City to advance an effort to safely phase out oil and gas extraction by prohibiting and making it a nonconforming use. It is an urgent catalyst to a larger citywide effort to phase out oil drilling in Los Angeles, focused narrowly on prohibiting this incompatible land use sooner rather than later. DCP recognizes that a cleanup and remediation policy needs to be addressed on a citywide basis." Staff Report, P-6.

The City also admits that further ordinance amendments are reasonably foreseeable as a result of the initial "project":

- "Once a well ceases operations, it is **reasonably foreseeable** that the process of abandonment should occur." Staff Report, A-3 (emphasis added).

- "In addition to this proposed Ordinance, City Council has also instructed OPNGAS to develop policies for the timely abandonment and remediation of existing well sites within three to five years of sites ceasing active oil production, with the intention of ensuring oil companies bear the responsibility for abandonment and remediation. . . .While the adoption of the Ordinance [Amendment] would accomplish a significant milestone in initiating the phase-out period, DCP will continue to consult with OPNGAS to conduct the necessary research on site cleanup and remediation policies, leaving open the possibility of future regulatory changes to the Zoning Code, if appropriate." Staff Report, P-6.

- "OPNGAS has been tasked with preparing an amortization study to determine how long existing operators need to recoup their costs and to determine whether individual wells can shut down sooner than 20 years. If the results of the amortization study find that individual wells can recoup their investments sooner, then the Code would be amended to reflect those timeframes." Staff Report, A-3.

- "In order to evaluate whether or not this 20-year period is the appropriate time frame, the Mayor and City Council, as part of CF 17-0447, directed OPNGAS to prepare an amortization study to determine whether this existing amortization period should be amended. The City is in the process of securing a consultant to prepare the study. Depending on the results of this study, future code amendments may require some or all wells to shut down sooner, in instances when the operator may recoup their capital investments prior to the 20-year amortization period currently embedded in the Zoning Code." Staff Report, P-2.

The City further acknowledges that the Proposed Ordinance fails to include a necessary definition for the term "maintenance." Rather than provide the definition now to avoid piecemealing, the City leaves that also for another day under the guise of regulatory guidance:

- "Separately from this Ordinance, DCP's Office of Zoning Administration is preparing a Zoning Administrator's Interpretation on the types of oil-related activities that constitute maintenance. The definition of maintenance is being addressed separately from the Ordinance because of the present need to clarify that maintenance activities, including acidization, are within the oversight of the Zoning Administrator. Once final, this guidance would immediately apply to all oil drilling activities. It would further clarify the types of maintenance activities prohibited under the Ordinance, with limited exceptions to prevent or respond to threats to public health, safety, or the environment." Staff Report, P-3.

Similarly, the City leaves for future determination and analysis the environmental impacts of the future condition of the former oil sites, including how those compare to the current oil operations:

- Given the varied timeline of individual well abandonment and the fact the Ordinance does not establish any regulations related to well site remediation or redevelopment (except where mitigation measures are required . . .), it would be speculative to contemplate when site remediation would occur after the wells are abandoned and the types of redevelopment and future land uses that may occur on former drill sites. What might get built and at what intensity or scale is not possible to identify or analyze at this time . . . The analysis does not examine impacts from remediation and/or future development. MND, pp. 31-32.

In *Laurel Heights Improvement Association v. Regents of University of Cal.* (1988) 47 Cal.3d 376, 396, the Supreme Court established the following test for illegal piecemealing: "We hold that an EIR must include an analysis of the environmental effects of future expansion or other action if: (1) it is a reasonably foreseeable consequence of the initial project; and (2) the future expansion or action will be significant in that it will likely change the scope or nature of the initial project or its environmental effects." Applying this test, the City unquestionably is committing illegal piecemealing in its draft MND by expressly omitting—and leaving for further ordinances and regulatory decisions—the reasonably foreseeable consequences of the Proposed Ordinance and the changes to scope and nature thereof, including the environmental effects.

Under the first prong of *Laurel Heights*, and as set out in the quotes from the Staff Report and MND above, the City concedes that a "reasonably foreseeable consequence" of the Proposed Ordinance is more ordinance amendments as to plugging, abandonment and remediation; amortization; and future use of former oil sites. Indeed, the City even uses the word "reasonably foreseeable" in describing the abandonment work that will follow cessation of operations. Staff Report A-3. Similarly, the City admits that it needs a definition of "maintenance" and thus the missing definition obviously is "reasonably foreseeable consequence" of the initial "project" and certainly serves no independent purpose. Even though a reasonable consequence of phasing-out oil operations in the City is that the property will be put to another use or otherwise suffer urban decay, the MND further fails to analyze these environmental effects, as discussed in more detail below in the next section of this letter. Simply put, the City knows that it is preparing an environmental document that has not fully disclosed and analyzed the "reasonably foreseeable" scope of the true, intended project, or the "whole" of the action to phase-out oil operations.

Regarding the second prong of the *Laurel Heights* test, it is clear that the City intends to, and is going to, further revise the City ordinances in ways that would, unequivocally, "change the scope or nature of the initial project or its environmental effects." 47 Cal.3d at 396. The ordinance changes and regulatory guidance that the City acknowledges will be forthcoming will further serve to phase-out oil operations. The City blatantly admits that the Proposed Ordinance is the first step in the project and changes will be coming on plugging, abandonment and remediation, amortization, what activities fall within the term "maintenance" and the future use of the former oil sites. The City's intent is clear—it wants to phase-out oil operations as quickly as it can, and more changes will be coming to make that happen. The City cannot avoid the obvious consequence of its intention, namely, that there will be a change in the scope or nature of the initial "project" to make that happen. The City expressly concedes this point in the Staff Report and MND, as noted above, thereby confirming that the second prong of the *Laurel Heights* test is met.

As discussed herein, there also will be changes in the environmental effects of the City's plan to develop procedures and timing for plugging, abandoning and remediation operations, shortening the amortization periods and thereby impacting mineral resources. These future phases serve no independent purpose or utility and by leaving them for another day, the MND drastically understates individual impacts related to the Project. For example, the MND fails to analyze impacts related to plugging and abandonment activities occurring on an accelerated schedule due to the yet undrafted plugging and abandonment requirements and because an amortization schedule, now set at 20 years but which the City acknowledges will likely be shorter, will cause oil and gas operators to plug and abandon wells, including multiple wells at the same time, in order to meet the City requirements. The MND also does not analyze the impacts of remediation operations, which will include removal of concrete pads and other infrastructure, all of which serve no independent utility aside from phasing out oil activities in the City. The second prong of the *Laurel Heights* test is also met for these additional reasons, and the City's illegal piecemealing is undeniable.

Given the above, the City can make no cogent argument that adoption of the Proposed Ordinance is not "a necessary first step to approval" of the later ordinances and regulatory guidance that the City concedes will be forthcoming to phase-out oil operations within the City limits. See *City of Carmel-by-the-Sea v. Bd. of Supers.* (1986) 183 Cal.App.3d 229, 244; see also *Banning Ranch*, *supra*, 211 Cal.App.4th at 1223 ("there may be improper piecemealing when the purpose of the reviewed project is to be the first step toward" some future action). Questions of project scope and piecemealing are not subject to the substantial evidence standard, but instead are analyzed as a question of law by a reviewing court. *Tuolumne Cnty. Citizens for Responsible Growth, Inc. v. City of Sonora* (2007) 155 Cal.App.4th 1214, 1223-24; *Black Property Owners Assoc. v. City of Berkeley* (1994) 22 Cal.App.4th 974, 984 ("Whether a particular activity constitutes a project in the first instance is a question of law."). Here, the City illegally, improperly, and knowingly limited the scope of the project analyzed in the MND by omitting analysis and environmental review of the changes that it intends to incorporate and acknowledges will be forthcoming.

B. Multiple Individual Impact Sections Also Are Deficient Because They Fail to Define an Adequate Baseline; Fail, by the MND's Own Admission, to Adequately Analyze Potential Impacts; and Fail to Analyze, or Properly Analyze, Impacts as Described in The City's Own Thresholds of Significance. Accordingly, the City Failed to Proceed in a Manner Required by Law, and Its Review is Not Supported by Substantial Evidence.

The City can approve the MND only if it finds no substantial evidence that the Project will have a significant effect on the environment. CEQA Guidelines, § 15074(b). CEQA requires that where there is substantial evidence supporting a fair argument that the Project could have a significant non-mitigable effect, the City must prepare an EIR. CEQA Guidelines, § 15064(f)(1). Even where there is "disagreement among expert opinion supported by the facts over the significance of an effect on the environment, the Lead Agency shall treat the effect as significant and shall prepare an EIR." CEQA Guidelines, § 15064(g).

Moreover, CEQA requires that a lead agency proceed in a manner required by law when preparing a CEQA document. As detailed below, the MND misstates or omits analysis required by CEQA, including analysis required under the CEQA thresholds of significance, including, but not limited to, any analysis of indirect impacts resulting from the Project. As stated by the California Supreme Court, "[n]oncompliance with substantive requirements of CEQA or noncompliance with information disclosure provisions which precludes relevant information from being presented to the public agency . . . may constitute prejudicial abuse of discretion." *Sierra Club v. County of Fresno* (2018) 6 Cal.5th 502, 515 (emphasis omitted).

1. The MND's Analysis of Impacts to Mineral Resources is Legally Inadequate and It Describes a Standard Inconsistent with the City's Own Thresholds of Significance.

It is undeniable that the Proposed Ordinance will impact the availability of mineral resources in the City and the State since the upfront and stated goal of the City is to stop oil production within the City limits, with the Proposed Ordinance being the first step in that process. "Mineral resources" are an environmental factor pursuant to CEQA, and the "loss of availability of a known mineral resource that would be a value to the region and the residents of the state" or the "loss of availability of a locally important mineral resource recovery site" constitutes an adverse environmental impact. CEQA Guidelines, Appendix G, § XII(a), (b). Public Resources Code § 21060.5 even expressly defines the "environment" to include "the physical conditions that exist within the area which will be affected by a proposed project, including land, air, water, *minerals*, flora, fauna, noise, or objects of historic or aesthetic significance." (Emphasis added.)

Here, the Proposed Ordinance *will* result in an increased loss of availability of mineral resources within the City that are of value to the region as acknowledged by the City's own land use policies and General Plan (see further discussion below and in the Land Use section of this letter). Further, the MND ignores the fact that the County of Los Angeles has enacted an ordinance similarly phasing out oil production in the unincorporated portions of the County, thereby further exacerbating the loss of availability of mineral resources of value to the region.

The Proposed Ordinance also *will* result in the loss of availability of known mineral resources that are of value to the State. The State has acknowledged the importance of protecting the oil and gas mineral resources located within its boundaries. "[T]o best meet oil and gas needs in this state, the [CalGEM] supervisor shall administer this division so as *to encourage the wise development of oil and gas resources*." Pub. Res. Code § 3106(d) (emphasis added). In particular, CalGEM shall supervise the "drilling, operation, maintenance, and abandonment of wells so as to permit the owners or operators of the wells to utilize all methods and practices known to the oil industry *for the purpose of increasing the ultimate recovery of underground hydrocarbons* and which, in the opinion of the supervisor, are suitable for this purpose in each proposed case." *Id*. § 3106(b) (emphasis added). Since the Proposed Ordinance seeks to stop recovery of underground hydrocarbon mineral resources rather that encourage their wise development and increase their ultimate recovery, it impacts the loss of availability of mineral resources that are of value to the State and the City is required to analyze the environmental impacts of the loss of availability those resources.

The MND's analysis of impacts to mineral resources is fundamentally flawed in that while the thresholds of significance require an analysis of whether the Project will result in the loss of *availability* of a mineral resource, the MND instead focuses on how much the implementation of the Project would impact current, existing *production* in the City. For example, the MND states that "annual cumulative oil production in the City was two percent of the available Statewide resource" and that "[t]his represents a small amount of the available Statewide resource." MND at 80. Accordingly, the MND concludes that "termination of oil and gas extraction would not represent the loss of a mineral resource of value to the region and the residents of the State." *Id.*

Again, the CEQA Guidelines require an analysis not of the loss of production, but of the loss of availability, of the known mineral resource. The City's own Oil and Gas Health Report dated July 25, 2019, which is incorporated herein by reference, confirms that *1.6 billion barrels* of recoverable oil and gas reserves remain beneath the City:

> Even after more than century of prolific production, the US Geological Survey estimates 1.6 billion barrels of recoverable oil remain in place beneath the City, *rivaling the reserves in the Middle Eastern countries, like Saudi Arabia, Iraq, and Kuwait 14,000 miles away*.[2]

Here, the MND itself even states that "[t]he Los Angeles geological basin has one of the highest concentrations of crude oil per acre in the world." MND at 20. Similarly, as noted in Warren's comment letter dated September 19, 2022, to the Planning Commission, which letter is incorporated herein by reference, Warren noted that a report by the US Geological Service dated February 2013 describes the Los Angeles Basin, which is partly encompassed by the City, as containing "one of the highest concentrations of crude oil in the world. Sixty-eight oil fields have been named . . . including 10 accumulations that each contain more than 1 billion barrels of oil. One of these, the Wilmington-Belmont, is the fourth largest oil field in the United States." USGS Fact Sheet 2012-3120, which is incorporated herein by reference.[3] Accordingly, based on this expert evidence alone it is undeniable that the Proposed Ordinance will have a significant impact on the availability of mineral resources and an EIR is thus required.

[2] https://clkrep.lacity.org/onlinedocs/2017/17-0447_rpt_BPW_07-29-2019.pdf at page 19.
[3] https://pubs.usgs.gov/fs/2012/3120/fs2012-3120.pdf.

Moreover, and as described in the Land Use section below, the MND cherry picks policies in support of its position that "petroleum is no longer considered an important mineral resource at the local level." MND at 80. This statement is contradicted by General Plan policies that the MND neglects to discuss, which provide that petroleum is an important local resource. For example, in discussing the Conservation Element of the General Plan, Proposed Finding 1 of the Planning Commission report describes three policies. These policies generally describe a need for encouraging energy conservation, supporting the ban on offshore drilling and protecting neighborhoods from potential accidents and subsidence associated with drilling and production.

However, listed directly above these policies, and not stated in the MND, is that the objective of these policies and the General Plan is to: "conserve petroleum resources and *enable appropriate, environmentally sensitive extraction."* City General Plan, Conservation Element at II-64 (emphasis added). The fact that the Proposed Ordinance would *ban extraction* rather than *enable extraction* clearly means that it is inconsistent with the General Plan and demonstrates that the City has already concluded that mineral resources are of value to the region and the residents of the State, and the same has been delineated in the General Plan and other land use plans. Indeed, one need only look at the practical realities of current life in the City of Los Angeles, including, among other things, the use of gasoline-powered vehicles, to see that oil still is an important resource to the region.

Again, the MND fails to conduct this part of the analysis under the required standard. It is unquestionable that an ordinance that terminates all oil and gas production in the City would result in the loss of availability of that resource, which importance has been described in State statutes and numerous documents, including the City's own General Plan and other land use plans.

2. The MND's Air Quality Analysis is Deeply Flawed and Inadequate Under the Law.

Expert opinion as described in the attached Air Study provided by Yorke Engineering, Inc. ("Yorke"), a copy of which is included as Attachment A and incorporated herein in full by reference, describes multiple deficiencies in the MND's analysis. For example, the MND includes a gross misstatement of the emissions related to equipment used for plugging and abandonment of wells, thus drastically understating emissions. Another example is the complete lack of any analysis of the health-related impacts related to the release of toxic air contaminants associated with equipment used for plugging and abandonment operations. Yorke notes, among other things, two critical mistakes made in the MND with regard to calculating criteria pollutants.

First, the MND lists equipment used for plugging and abandonment in order to calculate these emissions. However, the MND does not disclose the specifications for all the equipment used when analyzing the emissions, and no sources are cited for the horsepower and load factors used for the calculation of the equipment for abandonment operations. The MND drastically understates the horsepower ratings for the workover rig engine, calculating this as 33 bhp when the normal range for this type of equipment is 450 bhp to 1,000 bhp. The South Coast Air Quality Management District

(SCAQMD) provides that this type of equipment would have approximately 540 bhp and yet the MND uses 33 bhp. The MND also does not describe the necessary mud pump engine that is used in these types of operations. Accordingly, Yorke calculates that criteria emissions related to plugging and abandonment operations are approximately 6.1 times that described in the MND.

Second, the MND provides that up to 19 abandonments could be performed without exceeding the threshold for NOx. Applying proper calculations, under the Regional Significance Thresholds, only three concurrent abandonments could take place without exceeding the NOx threshold. Further, when using the SCAQAMD Localized Significance Threshold as stated in the MND, only one abandonment can be performed at any one time. As noted in Yorke's report, in order to remain under the significance threshold *solely as to Warren's operations* which includes 200+ wells, it would take ten years of continuous well abandonment work. Even if this were possible, which is unlikely given that well abandonment will likely be compressed in time either because operators seek to produce up to the end of the 20-year period or because the amortization period is shortened by the City following its study, this does not even take into account the approximately 2,000 other wells described in the MND as being located within the City that will need to be abandoned.[4]

The MND suffers from another major flaw in that it does not analyze health risk impacts, as required by CEQA, related to plugging and abandonment operations. It is unclear why the MND fails to do this as no explanation is provided. This is particularly concerning as to diesel particulate matter (DPM), which is associated with equipment used for plugging and abandonment operations. As noted in the Yorke report, DPM is "not easily dissipated" as described in the MND. Moreover, as it is a recognized carcinogen, the drastic increase in DPM emissions must be analyzed in terms of a health risk assessment. Yet the MND omits to do this in its entirety. Using the MND's own estimate of 0.19 lb./day alone exceeds the maximum significant cancer risk of 10 in a million while also exceeding the significance criteria related to acute and chronic health hazards. Using the correct power ratings of a workover rig and the inclusion of a mud pump engine, as described in the Yorke report, would result in an emission rate of 1.16 lb./day, which exceeds the maximum cancer risk of 10 in a million while passing the acute health hazard and all but one chronic health hazard. Thus, the cancer risk is 262 times higher than the level that is considered significant. Again, an EIR and much more detailed health risk assessments are needed to properly assess the Project's health risks.

The Yorke report notes that "health risks from DPM produced from the combustion of diesel fuel in the workover rig and other associated engines <u>are not addressed at all</u>." In *Sierra Club v. County of Fresno* (2018) 6 Cal.5th 502, 521 (2018), the California Supreme Court noted that the lead agency must make a reasonable effort to discuss the "general health effects associated with a particular pollutant and the estimated amount of that pollutant the project will likely produce." In that case, unlike here, the lead agency had provided a general discussion of the adverse health impacts related to pollutants, but this discussion did not connect this analysis to the actual levels of pollutant emitted

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[4] The failure to consider a compressed schedule also fatally undermines the MND's light and traffic sections in that both of these sections fail to consider a compressed abandonment schedule.

by the project. *Id.* at 522. Accordingly, the California Supreme Court found the EIR deficient both in that substantial evidence did not support the agency's conclusions and because the absence of relevant information was prejudicial.

Accordingly, the MND Air Quality Analysis section fails in its entirety to meet the minimum requirements of CEQA.

3. The MND's GHG Impacts Analysis is Inadequate Because It Understates the Resulting Emissions from Plugging and Abandonment Operations and Fails, in Its Entirety to Analyze Indirect Impacts That May Result from the Project.

The MND is deficient in that it fails to evaluate direct and indirect impacts related to GHG. This failure stems in part from the points already described in the Air Quality Analysis. For example, the MND describes the difficulty of doing an extensive analysis on the impacts and simply describes an analysis to "illustrate the potential scope" of the emissions. As with the Air Quality Analysis, the MND drastically understates emissions related to plugging and abandonment because of the failure to describe the proper bhp of the drill rig and the failure to include certain necessary equipment in the analysis.

As discussed further below, the MND must discuss the Projects' indirect impacts. CEQA Guidelines, §15064(d). This extends to GHG impacts, which the thresholds of significance acknowledge. The most obvious failure is the potential GHG emissions related to the use of the property after the oil production operations have ceased following the amortization period. This is a fairly easy analysis to undertake as is described in the Yorke report, which analyzes Warren's emissions as compared to a fast-food restaurant with a drive-thru among other uses. Yet the MND declines to make any type of analysis and instead states that such an analysis is too difficult even when a similar report done by Yorke was conducted over a couple of weeks.

The GHG Section also fails because of its apparent assumption that a decrease in production will necessarily result in a decrease in consumption of things like gasoline. The Yorke report points out a basic failure that the GHG Section fails to consider in that Warren transports its oil by pipeline to the local refinery where the oil is processed. The Project curtails oil production but in no way will reduce the amount of oil processed at the area refineries. Accordingly, a similar amount of oil will be trucked in from other sources or imported through the nearby port facilities. The MND fails to consider basic sources of information provided by the California Energy Commission ("CEC"), which references below are incorporated herein by reference. For example, there are multiple refineries located in the area, including some of the largest by production amounts in the State, and nothing in the Proposed Ordinance will reduce the amount of oil processed at these refineries.[5] The oil processed at these facilities will simply come from other, more distant, sources. The CEC information further indicates that foreign oil imports have

[5] https://www.energy.ca.gov/data-reports/energy-almanac/californias-petroleum-market/californias-oil-refineries

generally increased as production in California has decreased, and describes the amount of foreign oil processed at California refineries.[6] The CEC information is in no way speculative but is a reasonably foreseeable consequence of the Project. This situation is similar to that presented in *County Sanitation Dist. No. 2 v. County of Kern* (2005) 127 Cal.App.4th 1544, where the court held that an EIR was required when an ordinance passed restricting the disposal of sewage sludge because it failed to describe the reasonably foreseeable indirect impacts of the restriction, including the need for an alternate disposal site and things like increased hauling.

The GHG Section also fails to describe the impacts related to conflicts with other applicable plans or regulations, such as the Cap-And-Trade Program. Under this program and others, oil and gas production is strictly regulated to reduce GHG emissions. These are some of the most stringent restrictions in the world. The effect of the Project will be to shift production to other areas, including outside the State and overseas, which areas are not subject to these restrictions. Again, information on where these imports are likely to come from are listed in detail at the California Energy Commission website. For example, the CEC describes that as of 2021, Ecuador, Saudi Arabia and Iraq were responsible for more than 66% of California's imports.[7] Thus, production GHG emissions will increase at those sources, as will the emissions related to the transportation of oil to California, leading to increased emissions as the Ports since there are no intrastate pipelines transporting oil to the State. As discussed in a Los Angeles Times article that was published today (and is incorporated herein by reference), GHG and other air emissions already have increased significantly at these Ports.[8] They will further increase with importation of more oil to the region, yet the MND contains no discussion of these reasonably foreseeable indirect impacts. GHG emissions are unique under CEQA in that, unlike other impacts, the effects of GHG emissions are not localized. A metric ton of GHG emissions emitted in Saudi Arabia has the same effect as a metric ton of GHG emitted in California. Yet the MND fails to make any attempt to calculate the effect of shifting production and how this will impact California's various plans to reduce GHG impacts.

For all these reasons, the GHG Section is deficient and does not meet the requirements of CEQA. It is clear that for such a complicated issue, particularly where indirect impacts are key, an EIR must be prepared.

[6] https://www.energy.ca.gov/data-reports/energy-almanac/californias-petroleum-market/foreign-sources-crude-oil-imports/2020-0.
[7] https://www.energy.ca.gov/data-reports/energy-almanac/californias-petroleum-market/foreign-sources-crude-oil-imports.
[8] https://www.latimes.com/environment/story/2022-10-17/ports-blame-covid-19-for-spike-in-harmful-emissions.

4. **The MND's Land Use and Planning Analysis is Deficient Because It Omits City General Plan and Community Plan Elements That Support the Production of Oil and Gas.**

Pursuant to Government Code section 65860, a city zoning ordinance must be consistent with the city's general plan. The MND is required to address this consistency, and to show that "the various land uses authorized by the ordinance are compatible with the objectives, policies, general land uses, and programs specified in the plan." Gov't Code § 65860(a)(2); *see e.g., City of Los Angeles v. State of California* (1982) 138 Cal.App.3d 526, 532. As discussed below, the MND is deficient in that it fails to address the many policies of both the City General Plan and the various Community Plans that support the extraction and production of oil within the City. More importantly, the Proposed Ordinance is in fact not consistent with the various City plans.

The MND concludes that there is a less than significant "environmental impact due to a conflict with any land use plan, policy, or regulation adopted for the purpose of avoiding or mitigating an environmental effect." MND at 76. In drawing this conclusion, the MND asserts that it reviewed eight total City plans, including the Conservation Element of the General Plan, the Health Wellness and Equity Element to the General Plan, and the Wilmington-Harbor City Community Plan. MND at 76-77. It points to Table 4 as setting forth the "City Policies Supporting the Oil and Gas Ordinance," including certain land use policies, and concludes that the Ordinance is consistent and does not conflict with the policies identified in Table 4. However, Table 4 only lists four land use policies in support of the Ordinance—including one from the West Adams-Baldwin Hills-Leimert Community Plan and two from the Wilmington-Harbor City Community Plan—and fails to address the numerous City land use policies that support the continued extraction, maintenance, and production of oil and gas.

As an initial matter, the Proposed Ordinance will have an impact City-wide, there are wells in various locations all over the City, and the General Plan contains 35 community plans; yet the MND only lists land use policies from the West Adams-Baldwin Hills-Leimert Community Plan and the Wilmington-Harbor City Community Plan. Moreover, the policies cited contemplate continued oil and gas operations—as do many policies not included in the MND—and are therefore in conflict with a ban on such activities.

By way of just one example, a review of the Wilmington-Harbor City Community Plan reveals that the continued extraction of oil is clearly contemplated in the plan. Policy 3-4.6 supports "the consolidation of surface oil extraction operations, the landscaping or improvement of existing oil wells, and elimination of inactive and/or unneeded wells . . . increase compatibility between oil operations and other land uses . . . ." Further, Policy 3-5.1: "Regulate oil extraction activities and facilities in such a manner to enhance their compatibility with the surrounding community." Policy 3-5.2: ". . . require that existing and new oil well sites observe attractively landscaped and well maintained front yard setbacks . . . ." And Policy 3-5.4—which is cited in Table 4—provides for the consolidation of oil extraction operations to increase compatibility between oil activities and other land uses. All of these policies follow Objective 3-5 "[t]o ensure the public health, safety and welfare *while providing for reasonable utilization* of the area's oil and gas resources." (Emphasis added.) Accordingly, nothing in these policies is consistent with a total ban on oil production like that proposed in the Proposed Ordinance.

The MND also focuses on broad policies supporting discretionary review of *changes to* oil extraction sites, *reduction* of oil production, and general community health, without recognizing that those policies necessarily require the continuance of oil and gas operations. MND at 77. For example, the MND cites to Policy 5.4 of the Health Wellness and Equity Element of the General Plan, to protect communities' health from noxious activities, but fails to discuss that the same Element further provides that "[t]his policy calls for the City to work with operators to ensure that they have the required permits in place, increase its regulatory role and encourage conditions of approval that mitigate land use inconsistencies and conflicts." As a result, this section clearly assumes the continuance of extractions activities within the City.

Similarly, and as discussed above, the Conservation Element of the General Plan provides the Objective to "conserve petroleum resources and *enable appropriate, environmentally sensitive extraction* . . . so as to protect the petroleum resources for the use of future generations and to reduce the city's dependency on imported petroleum and petroleum products." City General Plan, Conservation Element at II-64 (emphasis added). This may only be read in the context of allowing continued extraction. The fact that the Proposed Ordinance would *ban extraction* rather than *enable extraction* clearly means that it is inconsistent with the General Plan. Not only is the Proposed Ordinance inconsistent with the General Plan and Community Plans and thus unlawful, but the MND omits or otherwise fails to consider critical information necessary for the City and public review of the Proposed Ordinance.

5. The MND's Noise Analysis is Legally Deficient Because It Understates Noise and Vibrations Related to Plugging and Abandonment Operations and It Does Not Describe an Enforceable Mitigation Measure for an Impact the MND Concedes is Potentially Significant.

The noise analysis in the MND is defective for multiple reasons. As with other sections in the MND, it fails to describe the baseline (here ambient noise) against which noise levels must be measured. In applying significance thresholds, the lead agency must consider both the absolute noise level associated with a project as well as the increase in the level of noise that will result from a project. *King & Gardiner Farms, LLC v. County of Kern* (2020) 45 Cal.App.5th 814, 887, 893.

As noted elsewhere in this letter, the analysis is flawed in that it assumes all well abandonment and plugging operations at a well site would be done sequentially (one by one) and intermittently. The effect of the City's past ordinances is that multiple wells exist on consolidated drill sites. For example, at Warren's Wilmington site, there are in excess of 200 wells on a 9.22-arce site. Well plugging and abandonment schedules will likely be condensed toward the end of the amortization period with multiple wells being plugged and abandoned at the same site at the same time. However, the noise analysis assumes only that "each well abandonment would last approximately two weeks . . . and on-site equipment would include one workover rig, one cement pump truck, one welder, and one tractor/loader/backhoe." MND at 82. The MND must analyze the noise impacts of operating multiple pieces of equipment involved in plugging and abandoning of multiple wells at the same time.[9] This is particularly true given that the MND has already concluded that a significant impact will result.[10]

The mitigation measure described as MM NOI-1 is also defective in that it fails to take into account multiple, simultaneous plugging and abandonment operations. Moreover, there is no discussion as to how the requirement would be implemented. Under CEQA, mitigation measures must be enforceable to be considered effective, yet the MND contains no information as to how the measure will be implemented or what will be required of operators. CEQA Guidelines, §15126.4(a)(2).[11]

Moreover, the MND further states that noise reduction would occur using best practices, including by scheduling abandonment activities to avoid operating several pieces of equipment simultaneously (as feasible), which causes high noise levels. MND at 84. The MND also concedes that the LAMC noise limitation does "not apply where compliance is technically infeasible." MND at 83. Accordingly, the noise analysis describes further mitigation without requiring an actual mitigation measure, and essentially concedes that it may not be feasible to avoid operating several pieces of equipment at the same time, which by the MND's admission will result in "high noise levels" and that the LAMC noise limitation "may not apply where it is technically infeasible."

The same problems in assuming low-levels of well plugging and abandonment operations also cause the MND to understate the vibration or ground borne noise levels. The analysis fails to take into account the compressed plugging and abandonment will have to occur in order to meet the City's amortization requirements. Accordingly, the MND fails to meet the basic requirements of CEQA.

6. The MND is Legally Deficient Because It Fails to Examine Any Cumulative Impacts Associated with the Project and Fails to Discuss Reasonably Foreseeable Indirect Impacts.

The MND also is legally deficient because it fails to describe any cumulative impacts associated with the Project, despite the fact that this is required under the Thresholds of Significance and CEQA. This flawed analysis may stem from the fact that the MND assumes that all impacts will be less than those associated with existing oil production operations. As noted throughout this letter, this is simply not true in that the MND only provides conclusory comments that existing operations

[9] The MND Transportation Section similarly fails to describe traffic impacts related to abandonment and fails to describe the potential hazards resulting from increased oil transportation to the refineries by truck.
[10] As noted in the comments on Air Quality Impacts, the MND also omits from its equipment list a mud truck and vastly understates the engine bhp of the workover rig.
[11] The mitigation measure described in the Hazards Section suffers from a similar flaw.

are worse and because the MND drastically understates impacts associated with plugging and abandonment operations. The MND's cumulative impacts analysis consists of four sentences. MND at 100. It includes the statement that "the impacts associated with individual well abandonments have been found to be less than significant." However, direct project-related impacts may be less than significant and still be cumulatively considerable. Yet there is no discussion of the effect of similar recently-enacted restrictions on oil operations such as SB 1137 and the new ordinance adopted by the County of Los Angeles, both of which will result in increased well abandonments. CEQA, however, does not restrict the required cumulative impacts analysis to similar projects but requires an analysis of other past, current, and probable future projects (including those unrelated to oil production restrictions). The MND remarkably contains no discussion of *any* other projects. The courts have found unlawful the conclusory approach used in the MND. The discussion must be more than a conclusion "devoid of any reasoned analysis." *Whitman v. Board of Supervisors*, 88 Cal. App. 3d 397, 411 (1979). Accordingly, the MND fails to meet the minimum standards of CEQA for cumulative impacts analysis.

Similarly, the MND also fails to discuss reasonably foreseeable indirect impacts. This requirement extends to the adoption of lead agency ordinances that result in changes to land use patterns. For example, in *County Sanitation Dist. No. 2 v. County of Kern* (2005) 127 Cal.App.4th 1544, the court held that an EIR was required when an ordinance was passed restricting the disposal of sewage sludge. The EIR was necessary to analyze an alternate disposal site and things like increased hauling.

Here, the MND is almost completely devoid of any basic analysis of indirect impacts. The MND uses the term "indirect" or "indirectly" approximately 22 times, and the vast majority of these mentions are related to a description of the CEQA thresholds, with the other mentions contained in conclusory statements that there are no indirect impacts. There is not even any discussion as to how the abandoned well sites may be used. For example, in Warren's situation the production site is located in a heavily-industrialized area next to the Port of Los Angeles. Yet there is no discussion as to the potential impacts that may result from the development of the sites as they are abandoned. Basic information, such as the zoning for the consolidated well sites, is not even included in the MND even though this information is readily available. Indirect effects include secondary effects. CEQA Guidelines, § 15358. If a direct change in the physical environment will cause another change in the environment, the secondary effect must be evaluated as an indirect effect of the project. CEQA Guidelines, § 15064(d). The impact analysis must also consider the potential for growth-inducing impacts. CEQA Guidelines, § 15358(a). Yet the MND fails to do this in its entirety.

The MND also fails to analyze the cumulative impacts from increased GHG and other air emissions at the nearby Ports. These emissions can be quantified, and have already increased significantly, as noted in a Los Angeles Times Article that was published today and which is incorporated herein by reference.[12] Nonetheless, the MND contains no discussion of the cumulative impacts from increased importation of oil to the State through those Ports, even though it is reasonably foreseeable that such activity will occur. Accordingly, the MND is deficient as matter of law.

7. The MND is Flawed Because It Consistently Fails to Describe, or Describes Inaccurately, the Existing Baseline.

A CEQA document must describe the physical environmental conditions in the vicinity of a proposed project as they exist at that time, which environmental setting will normally constitute the baseline physical conditions by which a lead agency will determine whether a project may have a significant impact on the environment. Without a comparison of existing baseline physical conditions to the conditions expected to be produced by a project, an initial study or environmental impact report (EIR) will not inform decision makers and the public of the project's significant environmental impacts, as CEQA mandates. *Taxpayers for Accountable School Bond Spending v. San Diego Unified School District* (2013) 215 Cal.App.4th 1013, 1047-1048.

The MND fails to meet this requirement in that it fails to describe, or describes inaccurately, the existing setting. For example, the MND describes an existing setting of oil and gas production, which the City analyzed in a report, and which indicates that "the report . . . shows that activities related to oil and gas operations have been associated with many potential negative health and safety impacts, especially when they occur in close proximity to sensitive uses." MND at 22.

It is on this basis that the City indicates it is going forward with the Proposed Ordinance and on this basis that the MND in multiple sections describes an erroneous, harmful existing setting based on oil and gas wells.

The statement in the MND is false and the CalGEM report referenced is based on areas outside of the City and, in most instances, even outside California.[13] California has conducted relevant studies, including under SB4, but the MND fails to acknowledge or use those studies. In fact, in 2019, the City of Los Angeles Office of Petroleum and Natural Gas Administration and Safety conducted an exhaustive review of government reports and studies and concluded that:

> There is a lack of empirical evidence correlating oil and gas operations within the City of Los Angeles to widespread negative health impacts. The lack of evidence of public health impacts from oil and natural gas operations has been demonstrated locally in multiple studies by the Los Angeles County Department of Public Health, the Los Angeles County Oil & Gas Strike Team,

[12] https://www.latimes.com/environment/story/2022-10-17/ports-blame-covid-19-for-spike-in-harmful-emissions.

[13] The report relies on data from Pennsylvania, Colorado, Oklahoma and Texas relating to unconventional drilling, which is different from the drilling conducted in the City. Moreover, the report ignores numerous studies of California operations and Health Risk Assessments relating thereto, and it does not appear that the report has even been finalized. It is thus improper to rely on this report in support of the MND.

> the South Coast Air Quality Management District and the comprehensive Kern County Environmental Impact Report and Health Risk Assessment.[14]

Accordingly, the MND proceeds in all of its analysis with a fundamentally flawed assumption as to the existing setting.

Moreover, multiple sections of the MND essentially state that it is too difficult to quantify the existing setting. For example, the Air Quality Section provides that "there remains substantial uncertainty in the emissions factors and calculation methodologies." MND at 42. In part, the MND states that this difficulty is due to the need for a "rigorous bottom-up approach [which] requires expert knowledge to apply and relies on detailed data which may be difficult and costly." *Id.* The MND thus declines to make such an assessment (apparently because it is too costly), but nevertheless concludes it has made a good faith effort "for illustrative purposes." *Id.* This is all despite the fact that oil production operations routinely report their emissions to the SCAQMD. The MND then makes the breathtaking statement that "the degree to which air quality emissions may be avoided under the Ordinance is not the basis for the impact determination." *Id.* This is exactly contrary to the purpose of CEQA in that the MND must determine the impacts related to the proposed Project. It is the delta between the existing setting and the emissions projected if the Project is adopted that goes to the very basis of CEQA, either because impacts would be decreased or increased significantly. Further, by failing to describe the existing setting, the MND fails to inform the public of the Project's impacts. The Air Quality Section goes on to state that "because the Ordinance would reduce long-term air quality emissions compared to existing emissions associated with oil and gas extraction . . . the Ordinance would not result in [a cumulative impact]." It is simply impossible to make such a conclusory assertion without quantifying the existing emissions.

It is evident that the City rushed to push forward the MND for consideration and thereby created an inaccurate and legally deficient document. This is acutely evident in its conclusory statements about the harm related to oil and gas operations in the City rather than providing any accurate quantitative analysis of these emissions. It is simply assumed that these emissions are harmful and drastically affecting local residents. Yet Warren's emissions are so low that they compare favorably to a fast-food restaurant with a drive-thru, a supermarket and fast-food restaurant (with no drive-thru) or a 200-unit low rise apartment complex. In fact, Warren's emissions of PM, a TAC, are drastically lower than these other uses. Yorke Report at 3. Warren's emissions are also drastically lower than those defined as requiring a major source permit and lower than those requiring offsets. Yorke Report at 2.

A similar non-substantive approach is also described in the MND's Greenhouse Gas Emissions Section. The language in this section is similar to that contained in the Air Quality Section in that

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[14] https://clkrep.lacity.org/onlinedocs/2017/17-0447_rpt_BPW_07-29-2019.pdf at page 145. This review is incorporated herein by reference.

the MND punts on any accurate analysis as to existing emissions and instead includes estimates for "illustrative purposes." MND at 61.

As described above, the Noise Section is similarly lacking in any kind of quantification of the Project baseline for such things as ambient sound conditions.

Accordingly, the MND is fundamentally flawed and does not comply with the basic legal requirements of CEQA, thereby depriving the public and City decision makers of relevant information needed for informed deliberation and consideration.

C. The MND is Also Deficient Because It Fails to Consider the Potential for Urban Decay, Which Requires an EIR.

"A lead agency must address the issue of urban decay in an EIR when a fair argument can be made that the proposed project will adversely affect the physical environment." *California Clean Energy Committee v. City of Woodland* (2014) 225 Cal.App.4th 173, 188. Although economic and social impacts of a proposed project typically fall outside of CEQA review, where those impacts could foreseeably result in an indirect environmental impact or physical change, such as urban decay, the lead agency must do an EIR to assess that impact. Moreover, the agency must adopt enforceable mitigation measures and a monitoring program to ensure those measures are enforced. "*The purpose of these requirements is to ensure that feasible mitigation measures will actually be implemented as a condition of development, and not merely adopted and then neglected or disregarded [ ].*" *Id. citing Federation of Hillside & Canyon Associations v. City of Los Angeles* (2000) 83 Cal.App.4th 1252, 1260-61 (emphasis in original).

Here—in part as a result of its piecemealing of the plugging, abandonment, remediation, and redevelopment requirements—the City has failed to consider the impact that hundreds of abandoned wells will have on the City's economy and eventually on its physical presence. It is reasonably foreseeable that the economic impact of banning drilling and driving the oil and gas industry out of the City will lead to abandoned sites, deterioration, and urban decay. Moreover, as it stands now, the Proposed Ordinance does not require any specific plugging, abandonment, and remediation work to be done. This means that not only does the MND fail to consider the environmental impacts of that plugging, abandonment and remediation work as discussed above, but nothing actually requires that work to be done in the first place. As drafted, it is therefore reasonably foreseeable that the Proposed Ordinance will result in hundreds, or perhaps thousands, of idle and abandoned wells throughout the City, resulting in inevitable urban decay and deterioration that is wholly unmitigated by the MND.

In other words, the City's attempts to address plugging, abandonment, and remediation work in a future ordinance or otherwise is not sufficient under CEQA because it is either (1) an admission that the City is improperly piecemealing, or (2) an improper, vague, and unenforceable attempt at future mitigation of a reasonably foreseeable indirect impact. *See Cal. Clean Energy Committee*, 225 Cal.App.4th at 196 (mitigation measures that did not commit agency to any enforceable "*actual* mitigation" or "concrete, measurable actions" to ameliorate the expected urban decay caused by the project are insufficient).

D. Conclusion.

For all the foregoing reasons, Warren urges the City to prepare an EIR and to do so on the whole of the project, not just this first phase of it. If the City fails to do so, it will be in violation of the law and subject to legal action for, among other things, failing to comply with CEQA. As described above, the MND is also deficient in that it does not describe a baseline and drastically understates both direct and indirect impacts related to the Project, particularly as to mineral resources and air quality impacts.[15]

Very truly yours,

DAY CARTER & MURPHY LLP

Thomas A. Henry

TAH:tl
Attachments

[15] Warren incorporates by reference its previous letter to the Planning Commission dated September 19, 2022, a copy of which is included as Attachment B. Warren also incorporates any written or oral comments made to the City in opposition to the City's adoption of the Project and the associated MND.

ATTACHMENT A

October 17, 2022

Ms. Tracy K. Hunckler
Day Carter & Murphy, LLP
3620 American River Drive, Suite 205
Sacramento, CA 95864
Direct: (916) 246-7306
Main: (916) 570-2500 x106
Fax: (916) 570-2525
E-mail: THunckler@DayCarterMurphy.com

Subject: Planning Commission Comment on LA City Ordinance

Dear Ms. Hunckler:

The equipment and operations at Warren E&P (Warren) do not emit significant quantities of air pollutants and do not pose a significant health risk to community residents or the public. Warren participates in annual emissions reporting to the South Coast Air Quality Management District (SCAQMD), which includes the mandatory reporting of air pollutants regulated by the Clean Air Act. Due to the low levels of facility emissions, Warren has never been required to obtain a federal operating air permit (Title V permit). Warren's reported emissions from 2021 are shown in Table 1 and are compared to the major source threshold are shown in Figure 1 below. All reported pollutants are less than 15% of the threshold.

Table 1: Warren Criteria Pollutant Emissions

	VOC/ROG	NOx	SOx	CO	PM
Warren E&P	2718	930	50.0	764	48.0

Further, Warren's low emissions of regulated pollutants exempt them from participation in the SCAQMD's RECLAIM program for large sources of oxides of nitrogen (NO_x) and sulfur oxides (SO_x). In addition, Warren has not been required to purchase emission offsets. The thresholds for offsets are lower than for major source permitting and are set by the SCAQMD. The purpose of offsets is to mitigate any emissions increase from a facility that would impact the local ambient air quality. Figure 2 shows the levels of Warren's emissions in comparison to the offset thresholds for the SCAQMD.

Figure 1: Major Source Threshold Comparison

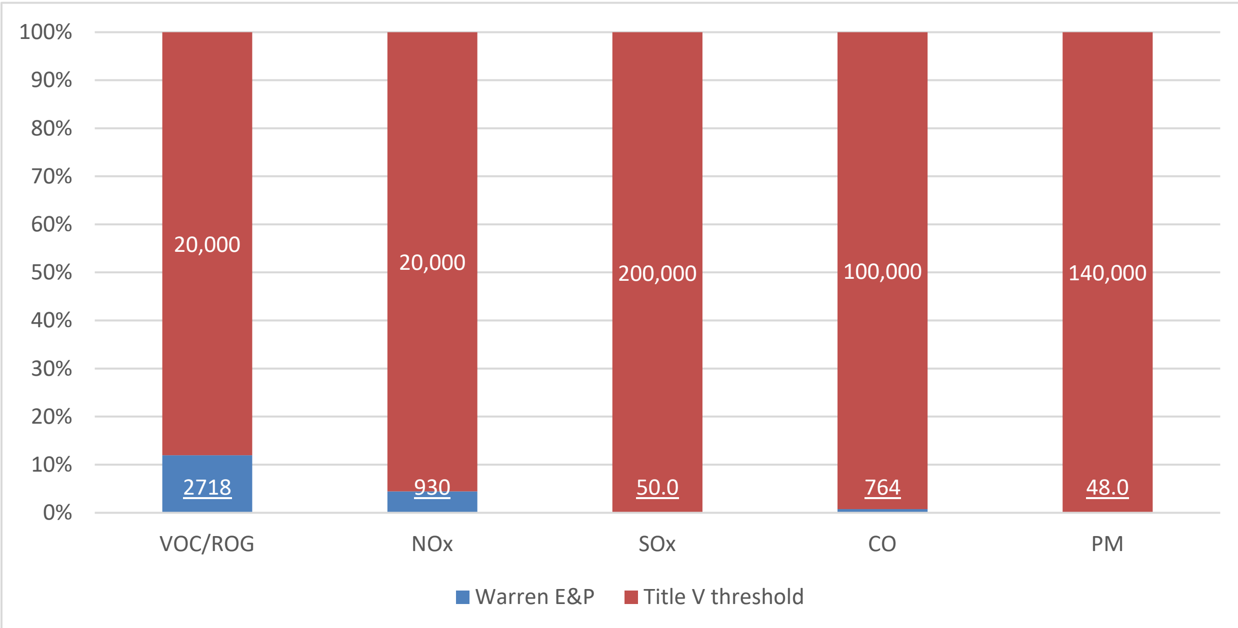
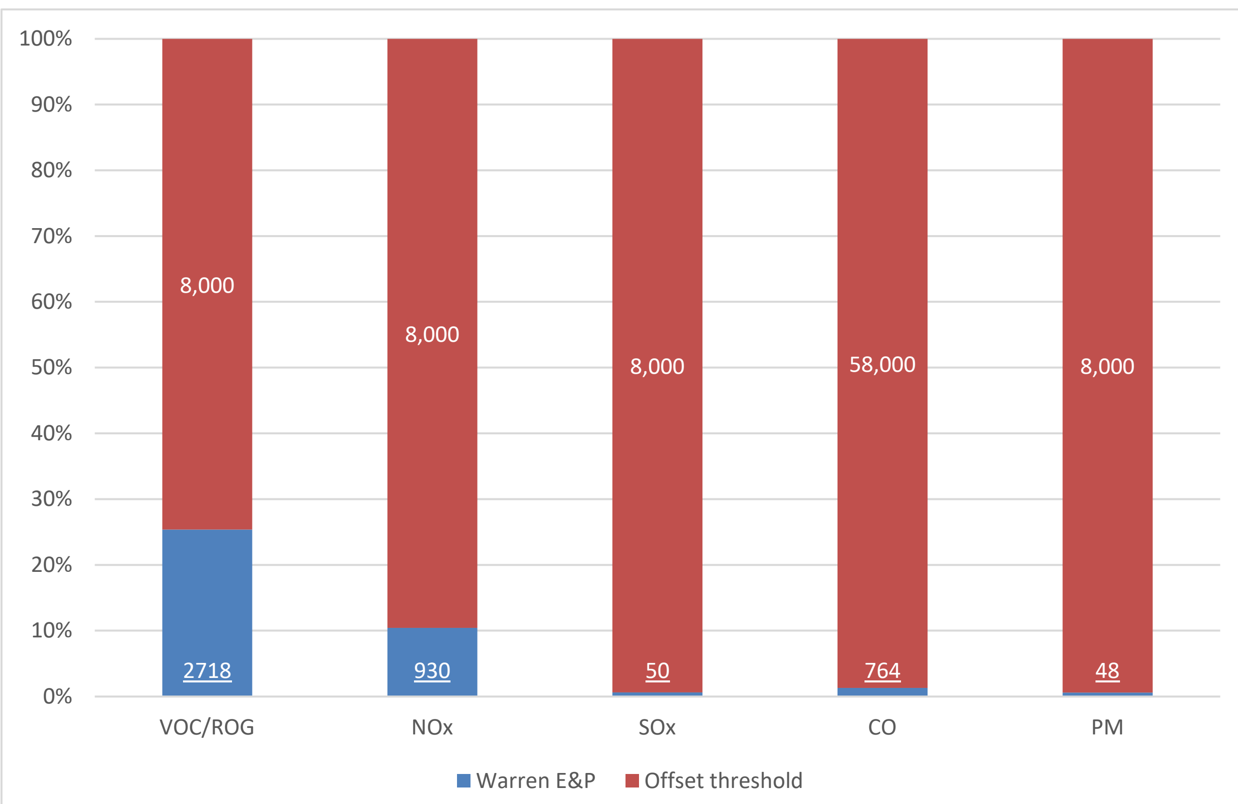


Figure 2: Emission Offset Limit Comparison



As a minor stationary source located in a heavily industrialized area of Wilmington, Warren has not permitted or installed new equipment or modified existing equipment in over six years. In addition, emissions are comparable to other types of business commonly found around Warren. Calculations of expected annual operational emissions from a supermarket and fast-food restaurant without a drive-thru, a fast-food restaurant with a drive-thru, and a 200-unit low-rise apartment complex performed using CalEEMod[1] are shown compared with the annual emissions from Warren as reported in 2021 (Figure 3). The emissions associated with the other types of businesses come from natural gas combustion used for heating and hot water, fuel-powered landscaping equipment, paints and coatings for regular building maintenance, and household products used by residents and cleaning staff.

Warren's emissions of NO_x and CO, two criteria pollutants associated with combustion sources, are lower than all other comparable sites. Its volatile organic compound (VOC) emissions are on the same order of magnitude as the other types of business. VOCs from Warren include any fugitive emissions associated with wells, as well as VOCs from combustion sources.

Figure 3: Site Comparisons

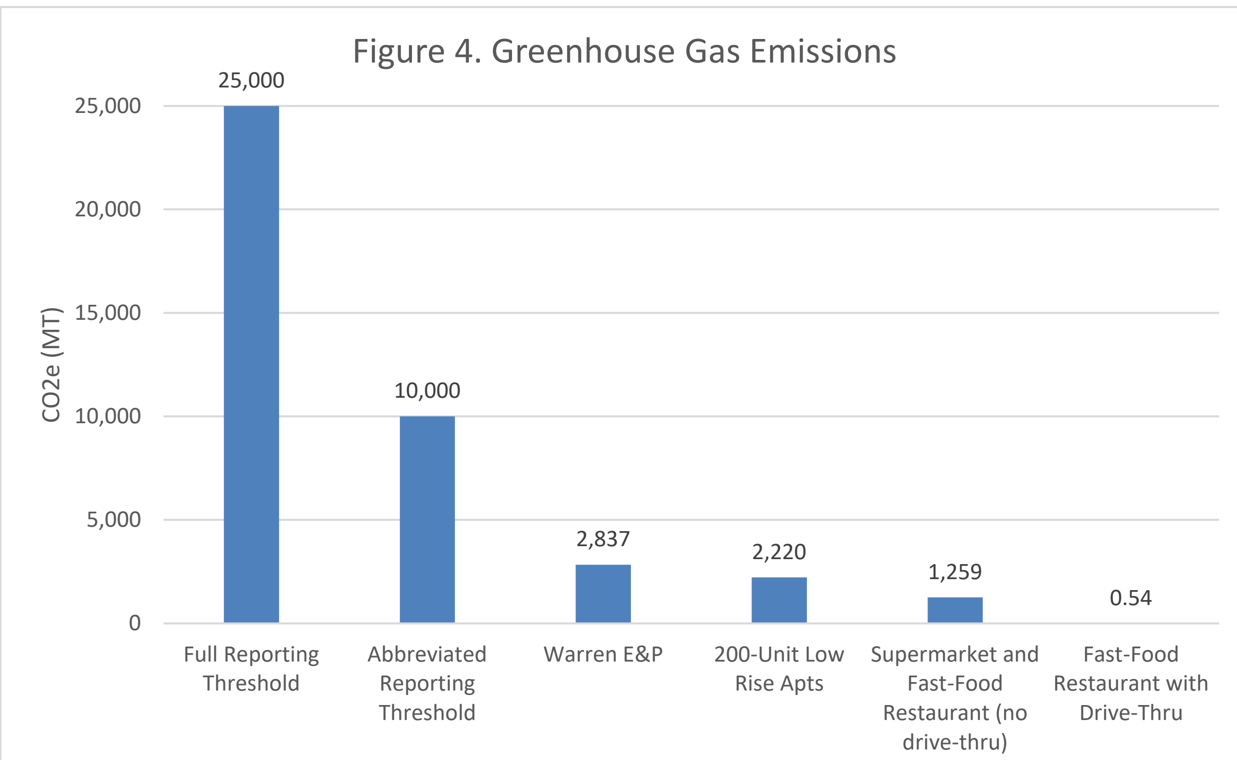
[1] The California Emissions Estimator Model (CalEEMod) is a statewide land use emissions computer model designed to provide a uniform platform for government agencies, land use planners, and environmental professionals to quantify potential criteria pollutant and greenhouse gas (GHG) emissions associated with both construction and operations from a variety of land use projects.

GREENHOUSE GAS EMISSIONS

Greenhouse gas (GHG) emissions contribute to global warming, and the contribution from Warren comes from the combustion of natural gas, which produces CO_2, as well as from fugitive methane emissions associated with the wells and drilling components. Warren's emissions are well below the thresholds for mandatory reporting to CARB and the U.S. EPA, as shown in Figure 4. In addition, when compared to other types of land use that might be put in place should the facility be fully decommissioned, such as low-rise apartment housing, the associated annual greenhouse gas emissions would be on the same order of magnitude.

Warren's production currently travels by pipeline to a nearby refinery for processing. If production ceases at the facility, crude will need to be transported into the area by some other means, likely by truck which would increase GHG emissions. The Draft Ordinance's Mitigated Negative Declaration does not address GHG associated with fuel transportation, only reduction in worker commutes and fugitive emissions. Additional analysis should be done in order to accurately quantify the GHG emissions.

Figure 4: Greenhouse Gas Emissions



TOXIC AIR CONTAMINANTS

In addition to regulated pollutants, Warren has consistently reported low emissions of toxic air contaminants. The facility routinely reports a detailed air toxics emissions inventory to the SCAQMD, and yet has never been required by the SCAQMD to prepare a Health Risk Assessment (HRA) because of low emissions. Combustion emissions from Warren operations are comparable to those shown above based on motor vehicle operations at supermarkets, fast-food restaurants, and 200-unit low rise apartments. Fugitive emissions that are associated with Warren operations have been most recently reported as low emissions that contribute to a low health risk. For example, annual benzene emissions for 2021 are estimated as approximately 6.24 pounds and are well below any cancer risk significance threshold based on a 100 meter or greater distance. This low health risk estimate is consistent with the SCAQMD's determination in all prior reporting years that a facility-wide health risk assessment is not required.

COMPARISON OF ABANDONMENT POLICY IN DRAFT ORDINANCE VERSUS CALGEM REGULATIONS

The Draft Ordinance states that petroleum is not a mineral resource. This is contrary to the primary regulatory responsibility given to the California Department of Conservation's Geologic Energy Management Division (CalGEM) which provides protection to public health, safety, and the environment while overseeing the state's oil, natural gas, and geothermal industries. This basic goal of CalGEM is given to the agency by state law as follows:

> *"[T]o best meet oil and gas needs in this state, the [CalGEM] supervisor shall administer this division so as to encourage the wise development of oil and gas resources." Pub. Res. Code § 3106(d). In particular, CalGEM shall supervise the "drilling, operation, maintenance, and abandonment of wells so as to permit the owners or operators of the wells to utilize all methods and practices known to the oil industry for the purpose of increasing the ultimate recovery of underground hydrocarbons and which, in the opinion of the supervisor, are suitable for this purpose in each proposed case." Id. § 3106(b).*

CalGEM's regulations have been instituted over decades of governmental studies, legislative action, public participation, and industry input to form and implement regulations that govern every aspect of oil and gas production. CalGEM's regulatory structure with full jurisdiction over the oil and gas industry is extensive and rigorous, in terms of permitting requirements, testing requirements, operational requirements and abandonment procedures.

One major difference between the Draft Ordinance's and CalGEM's defined applicability for when a well becomes idle is as follows:

- The Draft Ordinance states that if a well's operation is discontinued or idled for a continuous period of six months, such use shall be deemed terminated. Thus, the well is designated as permanently idle and from that point on, the timeline toward abandonment starts. In current practice, however, the operation of a well can be ceased for over six months due to supply chain delays in getting the appropriate parts for repair or maintenance just to continue normal operations. The ordinance does not consider such typical scenarios and makes those wells, that were idle only due to waiting for repair or maintenance, as permanently idled and on a timeline to abandonment.
- CalGEM Regulations define a well as idle if it has been inactive for at least two years with no production of oil and gas. CalGEM's Idle Well Management regulations deal with all long-term idle wells, defined as being over eight years idle. For these wells, there are strict requirements for periodic testing including fluid level testing, casing pressure testing and mechanical integrity testing. For all long-term idle wells, these strict requirements help assure well integrity during the period prior to plugging and abandonment. If the operator intends to return the well to production or injection, it may do so only after approval from

CalGEM and passing various operational and integrity tests. Continuous production or injection for six months after approval is required to return the well to active status.

The Draft Ordinance makes oil and gas production and injection a non-conforming use that must be eliminated, requiring all operations and oil production to cease within 20 years. The Draft Ordinance expects that many operators will choose to abandon their wells earlier in that timeline consistent with "all applicable local state and federal laws, regulations, rules and standards." The process of dealing with long-term idle wells and abandonment procedures are already greatly detailed in CalGEM's compilation of Statutes and Regulations, which include workable timelines for abandonment.

Companies with long-term idle wells are required to plug and abandon at least 4% to 6% of their long-term idle wells each year. The Draft Ordinance provides no correlation to CalGEM's regulations or statutes, and conflicts with some of the definitions, the primary one being the definition of "idle" as being over six months of no production or injection, whereas CalGEM defines "idle" as being over two years of no production or injection. The Draft Ordinance does not allow a return to production after becoming idle, while CalGEM does provide a process of returning to an active status after being idle.

In 2019, CalGEM revised its idle well regulations to create far more stringent test requirements that better protect public safety and the environment from potential threats posed by idle wells. Tests that must be performed include casing pressure tests, mechanical integrity tests, fluid level tests, and clean-out tags. Many of the current problems with long-term idle wells and also plugged and abandoned wells, which were previously plugged and abandoned under less stringent regulations, are addressed by the revised Idle Well Management regulations.

If all wells must essentially cease operations as a non-conforming use within twenty years, not only will it have great direct effects on the industry, but also on the probable glut of abandonment work that will result at the end of this 20-year period.

The Draft Ordinance prohibits certain types of maintenance and re-work on wells, as it interprets this as encouraging production of oil. In practice, maintenance and re-work is required to at least maintain stable viability of the resources, which is the goal of both CalGEM and the operators. Maintenance also serves to reduce the potential for a leak or spill or other adverse event that could impact the local community or the surrounding environment. The Draft Ordinance does not clearly define what activities constitute prohibited maintenance, which would cause varying interpretations by operators and agencies.

DEFICIENCIES IN THE DRAFT ORDINANCE'S MITIGATED NEGATIVE DECLARATION (MND)

The MND and its supporting Air Quality and GHG Technical Report is inadequate for several reasons. First, the MND significantly underestimates the potential impacts for following an intensive and accelerated abandonment program, including not only the quantity of emissions that could exceed significance thresholds for criteria pollutants and GHG, but also for toxic air contaminants (TAC) that may have acute, chronic, and carcinogenic health effects. In addition, the Draft Ordinance's MND does not include an assessment of human health for its proposed mandated abandonment program on either a per-well basis or on the full inventory of city wells to be abandoned. It only presents criteria and GHG emissions for one well abandonment at a time, without a health risk assessment. Using references to several studies, the Draft Ordinance's MND cites area-wide emissions for fugitive components and wellheads, but only for criteria and GHG emissions. Toxic air contaminants are not quantitatively discussed or determined.

When determining whether a threshold for a criteria pollutant, a toxic pollutant such as DPM, or GHG is being exceeded, the analyses should use the most representative equipment ratings and assumptions for the equipment to be used during abandonment activities. The Draft Ordinance's MND used averages for many of their input values. If significance thresholds are exceeded after correction and refinement of the MND's technical report, to pass the Ordinance when a significance level is exceeded, the City Council will have to approve an Overriding Consideration that the Potentially Significant Impacts posed by abandonment activities exceed those from fugitive emissions from oil fields' wells and well cellars.

In addition, the Draft Ordinance's MND does not disclose the specifications for all the equipment used when analyzing abandonment emissions per well. There are no sources cited for the horsepower or load factors used in the CalEEMod calculations for the equipment items assumed for abandonment activities.

Most importantly, an incorrect horsepower rating for the main equipment item, the workover rig engine, used during abandonment activities is used in the CalEEMod analysis. The MND's technical report shows that 33 bhp was used for the workover rig engine's power rating, whereas the normal range for a self-propelled mobile tractor-based workover rig is 450 bhp to 1,000 bhp. From other available Environmental Impact Reports prepared by the South Coast Air Quality Management District (SCAQMD), a standard rig used for operations that would include abandonment, well maintenance, and drilling, is approximately 540 bhp[2i]. Therefore, the workover rig emissions are roughly sixteen times the emissions calculated by CalEEMod in the MND. In addition, per research on typical equipment on-hand during abandonment activities, a mud pump engine is included. Adding a typical mud pump engine, which has a similar sized engine to the workover rig engine, produces a roughly six-fold increase in the emissions of criteria, toxic and GHG pollutants during abandonment activities.

COMPARISON OF ABANDONMENT EMISSIONS IN THE DRAFT ORDINANCE'S MND VERSUS THE MND REVISED TO CORRECT INFORMATION

Attachment 1 includes tables presenting the emissions of criteria emissions, DPM emissions (a toxic air contaminant), and GHG are shown in the attachments. The tables use most of the assumptions used in the Draft Ordinance's MND, including a schedule of five working days over a period of two weeks for a typical abandonment event; the offroad equipment necessary for abandonment including a workover rig engine, cement pump engine, welding engine and one tractor/loader/backhoe engine; and worker trips in both normal light-duty and heavy-duty vehicles to and from the jobsite. All the data and assumptions were input to CalEEMod originally for presentation in the Draft Ordinance's MND.

[2] South Coast Air Quality Management District, Final Environmental Impact Report for: Breitburn Santa Fe Springs Blocks400/700 Upgrade Project, August 2015. State Clearinghouse No.: 2014121014. Appendix B - Air Quality and Greenhouse Gases Technical Report; Table B-16

The revisions to these calculations determined by CalEEMod include only the correction of the power rating of the workover rig engine from 33 bhp to 540 bhp, and the inclusion of one mud pump engine, also an offroad equipment item with a power rating of 540 bhp. There were no changes to the time of usage or load factor of each equipment item included in the original MND's CalEEMod analysis. The calculated increase in emissions from the original MND to the revised MND is due solely to the correct power rating and the inclusion of one mud pump engine, by prorating the combined bhp-hr for all abandonment offroad equipment. The emissions of each criteria pollutant, including PM_{10}, increased by 6.11 times. Yorke assumes that all the PM_{10} is DPM. Since the only combustion sources contributing particulate emissions during abandonment are diesel-powered, this assumption is sound.

Each criteria pollutant's emissions therefore are increased by 6.11 times. Although the significance thresholds for both the Regional Significance Thresholds and the SCAQMD Localized Significance Thresholds are not exceeded for any single abandonment event, the number of abandonment events that can be performed concurrently at the facility are decreased substantially.

The Draft Ordinance's MND determined that when comparing the number of concurrent abandonments to the Regional Significance Thresholds, up to nineteen abandonments could be performed without exceeding the threshold for NO_x, the criteria pollutant that approached its threshold the closest. The revised MND analysis, using the correct power rating of the workover rig engine and including the mud pump engine, causes the number of allowable concurrent abandonments to drop from nineteen to three abandonments.

When comparing the allowable concurrent abandonments to the SCAQMD Localized Significance Threshold stated in the Draft Ordinance's MND, only one abandonment can be performed at any one time when using the correct power ratings and equipment, compared to nine abandonments in the Draft Ordinance's MND.

From a review of CalGEM's Wellstar database of active and idle production and injection/water disposal wells, Warren E&P currently has 165 active wells and 79 idle wells at its WTU facility at 625 E. Anaheim Street in Wilmington. Prorating the number of abandonments that can be performed concurrently during one-year yields 26 wells per year that can be abandoned without exceeding the SCAQMD Localized Significance Threshold stated in the Draft Ordinance's MND. Therefore, it would take almost ten years of continuous abandonment activity for Warren E&P to abandon its existing idle wells and the remaining active wells once the Draft Ordinance's amortization period dictates those active wells must also be abandoned. As there are multiple oil and gas production companies that will be required to meet the same thresholds and abandonment requirements as Warren E&P. Warren E&P is just one facility; the emissions of criteria, toxic and GHG pollutants will be replicated many times over from similar oil and gas production companies that also have wells throughout the City. Community residents may experience significant health risks that will be produced by an accelerated abandonment program, especially for those community residents living in close proximity to the abandonment locations. Health risks determined from many abandonments will be cumulative and will show a far greater area-wide impact than an assessment that only focuses on a per-well emissions basis.

SCAQMD TIER 2 SCREENING-LEVEL HEALTH RISK ASSESSMENT FOR DPM EMISSIONS

The MND states that DPM emissions from abandonment activities are short-term and are easily dissipated in the environment. In fact, since DPM is classified as a TAC, it is more likely to pose a health risk to the community than alleged health risks due to fugitive emissions from oil and gas production well heads and well cellars. Combustion emissions of DPM will be more concentrated at all abandonment locations. The workover rig and associated offroad combustion equipment are large point sources at specific locations, rather than area sources such as fugitive emission from smaller non-combustion sources spread throughout the oil field.

The MND also includes a comment that the long-term health risks from the abandonment of each well are insignificant. However, this this does not account for the cumulative impact of the health risks for the abandonment of all wells. As DPM is recognized as a carcinogen which also poses chronic health impacts to the respiratory system, the omission of a Health Risk Assessment (HRA) to assess DPM in the MND is a deficiency that needs to be addressed.

The SCAQMD has defined CEQA health risk thresholds for long-term and short-term health impacts. The health risks associated with DPM are the long-term cancer risk, cancer burden risk, and chronic health hazard (CHH) index to the respiratory system; DPM does not have a listed health risk impact for short-term acute health hazard risks. The SCAQMD CEQA thresholds for these health risks are the cancer risk of 10 in a million and the CHH index of 1 (CEQA does not define a threshold of significance for cancer burden).

Yorke Engineering has prepared a Tier 2 screening-level HRA for DPM emissions based on SCAQMD procedures from both the existing MND, with its incorrect lower rating of 33 bhp for the workover rig engine, and a corrected rating of 540 bhp for the workover rig engine. As shown in the attachment presenting the HRA outputs, both scenarios fail and are shown to be Potentially Significant Impacts to human health due to the emissions of DPM. Therefore, the daily DPM emissions from one abandonment event, and thus increased cancer risk due to abandonment activities necessary to comply with the Draft Ordinance's abandonment requirements, may in fact outweigh any perceived reduction of risk from fugitive emissions from oil and gas production wells.

Attachment 2 presents the results of Yorke's screening HRA for DPM emissions, which again were not analyzed in the Draft Ordinance's MND. The results show that the DPM emission rate of 0.19 lb/day as cited in the Draft Ordinance's MND exceeds the maximum cancer risk of 10 in a million, while falling below the limit of 1 for the CHH index. The cancer risk at 0.19 lb/day of DPM emissions produces a calculated cancer risk that is 42.9 times higher than the threshold level that would not result in a significant impact. At the very least, a more detailed HRA in accordance with the SCAQMD CEQA guidelines would be required to prove that a Potentially Significant Impact would not result. A summary of the screening health risk results for the existing MND is shown below.

Table 1: Screening HRA Results – Existing MND

Risk Parameter	Risk Level	Threshold	Threshold Exceeded?
Cancer Risk (in one million)	429	10	Yes
Chronic Health Hazard Index (HIC)	0.25	1	No

Notes:

1. Cancer risk based on 2-year exposure.
2. Thresholds are based on SCAQMD CEQA Air Quality Guidelines.

Attachment 3 presents a screening HRA prepared by Yorke for DPM emissions calculated from the revised data that was included in the MND, where the correct power rating of the workover rig was used in addition to the inclusion of a mud pump engine. The revised MND shows that the DPM emission rate of 1.16 lb/day exceeds the maximum cancer risk of 10 in a million and the CHH index of 1. The cancer risk at 1.16 lb/day of DPM emissions produces a calculated cancer risk that is 262 times higher than a level that would not be a significant impact. Again, further detailed HRAs including those using more advanced computer modeling of weather and health factors would be required to a prove that a Potentially Significant Impact would not result. A summary of the screening health risk results for the revised MND are shown below.

Table 2: Screening HRA Results – Existing MND

Risk Parameter	Risk Level	Threshold	Threshold Exceeded?
Cancer Risk (in one million)	2,619	10	Yes
Chronic Health Hazard Index (HIC)	1.53	1	Yes

Notes:

1. Cancer risk based on 2-year exposure.
2. Thresholds are based on SCAQMD CEQA Air Quality Guidelines.

Although cancer burden does not have an SCAQMD CEQA threshold of significant impact, cancer burden does have a threshold of 0.5 under the SCAQMD air toxics reporting program as well as their permitting program for public notification requirements. For both scenarios presented above, cancer burden health risks were estimated to be significantly higher than 0.5. Based on the cancer risk and the distance to receptors in the MND, the cancer burden health risk would be well above the air toxics reporting and public notification threshold.

CONCLUSIONS

Warren complies with all regional, state, and federal rules and regulations and has obtained the appropriate air quality permits for all operating equipment. Restricting maintenance, testing, and repair of the existing equipment would not represent an emission reduction or result in any improved air quality for the area or the region.

The Draft Ordinance's MND had several notable deficiencies including the use of incorrect data when calculating emissions of criteria, toxic and GHG emissions. It also tended to minimize impacts that will result from a significant increase in accelerated abandonment operations compared to those abandonment operations that are systematically scheduled and regulated by CalGEM. Also, certain pollutants that are toxic and carcinogenic, such as DPM and other combustion TACs, will be produced in much larger quantities, and will not be controlled solely by using regulations that limit engine idling to five minutes as suggested in the Draft Ordinance's Initial Study. Elapsed time for active equipment operation for abandonment activities will be far greater than idling time, as idling only occurs during standby status or equipment downtime.

Perhaps the largest deficiency in the Draft Ordinance's MND is the absence of any calculated health risks associated with the drastically increased emissions of DPM from abandonment activities due to the Draft Ordinance itself. When comparing the perceived health risks of fugitive emissions, which are generally emitted as an area source and do not involve any combustion of fuels such as diesel, to the increased emissions of DPM, the resulting real health risks from DPM produced from the combustion of diesel fuel in the workover rig and other associated engines are not addressed at all. Further studies should be completed on the real and expected impacts of increased DPM emissions on human health and the environment, especially in those areas where most abandonment activities will occur.

In general, Warren's emissions are low and do not exceed thresholds that would qualify the facility as a major source requiring a federal facility operating permit, or that would require acquisition of emission offsets. Due to its low emissions, Warren has not had to submit a full health risk assessment to the SCAQMD.

Warren is part of an oil and gas production industry that per the 2022 Draft SCAQMD Air Quality Management Plan (AQMP) produces less than 1 percent of the total emissions of criteria pollutants, including ROG, VOC, NOx and PM10, in the South Coast Air Basin.[3] The oil and gas industry is not listed as a top-ten significant source of pollution-emitting categories in the Draft AQMP, while off-road equipment is listed as the second-largest emitting category in the Draft AQMP. The addition of off-road equipment emissions from an accelerated abandonment program would only produce more such emissions in community areas that already see a large percentage of emissions from industrial activities. For example, the Ports of Long Beach and Los Angeles recently issued a report of emissions from port operations, showing annual emissions increases from 2020 to 2021 for DPM (up to 56%) and NOx (up to 54%)[4]. The accelerated phase-out of oil and gas production in the Los Angeles area would increase importation of oil from foreign nations, thus producing increased transportation emissions of DPM and NOx due to oil transport by tanker ships.

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[3] South Coast Air Quality Management District, Draft Air Quality Management Plan – 2022, Chapter 3 – Base Year and Future Emissions.

[4] Los Angeles Times, 10/17/2022, "Ports Blame Covid-19 for Surge in Harmful Emissions," https://www.latimes.com/environment/story/2022-10-17/ports-blame-covid-19-for-spike-in-harmful-emissions

In conclusion, Warren E&P finds that the Draft Ordinance's MND is deficient since it does not fully discuss the environmental effects of the increased emissions from off-road equipment in an accelerated abandonment program. The resulting health impacts from DPM emissions exceed the thresholds for carcinogenic and long-term chronic respiratory health risks. The MND failed to fully address immediate health risks for receptors for abandonment activities, since there was no health risk screening at all for DPM emissions in the Air Quality discussions of the Initial Study and the MND itself.

Should you have any questions or concerns, please contact me at (949) 426-4943.

Sincerely,

Don Barkley
Senior Engineer II
Yorke Engineering, LLC
DBarkley@YorkeEngr.com

Enclosures:

1. Attachment 1 – Emissions from Abandonment Activities / Existing MND
2. Attachment 2 – Emissions from Abandonment Activities / Revised MND
3. Attachment 3 – Health Risk Screening of Abandonment Activities / Existing MND
4. Attachment 3 – Health Risk Screening of Abandonment Activities / Revised MND

ATTACHMENT 1 – EMISSIONS FROM ABANDONMENT ACTIVITIES / EXISTING MND

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Abandonment Emissions Comparison - Proposed MND vs. Revised Proposed MND

Schedule		
Days per Week	5	5
Number of Weeks	2	2
Total Days per Abandonment	10	10

Construction Equipment Emissions - Abandonment Per Well	MND for Proposed City Ordinance										
	Quantity	Power, Bhp	Hours per Day	Bhp-hr	ROG - lb/day	NOx - lb/day	CO - lb/day	SOx - lb/day	PM10, lb/day	DPM, lb/day	GHG CO2e, MT/yr
Off-Road Equipment											
Workover Rig	1	33	8	264	0.51	4.69	5.79	0.01	0.19	0.19	3.88
Cement Pump Engine	1	367	1	367							
Welding Engine	1	84	6	504							
Tractor / Backhoe / Loader	1	84	6	504							
Mud Pump Engine	0	0	0	0							
				1,639							

Construction Vehicle Emissions - Abandonment Per Well	Vehicle Category	Vehicle Trips	Miles per Trip	ROG - lb/day	NOx - lb/day	CO - lb/day	SOx - lb/day	PM10, lb/day	DPM, lb/day	GHG CO2e, MT/yr
Worker Pick-Up Trucks	LDA, LDT1, LDT2	20	18.5	0.09	0.10	1.51	0.00	0.02	0.02	1.25
Vendor Truck	HHDT	6	10.2	0.01	0.31	0.14	0.01	0.02	0.02	1.05
Hauling Truck	HHDT	0	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
On-Site Truck	HHDT	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				0.61	5.10	7.44	0.02	0.23	0.23	6.18

Regional Significance Threshold	75	100	550	150	150	NA	NA
Exceeds Regional Significance Threshold?	No	No	No	No	No	No	No
SCAQMD Localized Significance Threshold (@ 25m)	NA	46	231	NA	4	4	NA
Exceeds SCAQMD Localized Significance Threshold?	NA	No	No	NA	No	No	No
Number of Abandonments Per Day Before Exceed Regional Significance Threshold	19						
Number of Abandonments Per Day Before Exceed SCAQMD Localized Significance	9						

ATTACHMENT 2 – EMISSIONS FROM ABANDONMENT ACTIVITIES / REVISED MND

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Abandonment Emissions Comparison - Proposed MND vs. Revised Proposed MND

Schedule		
Days per Week	5	5
Number of Weeks	2	2
Total Days per Abandonment	10	10

Construction Equipment Emissions - Abandonment Per Well	Revised MND to Correct Rig Bhp and Add Mud Pump Engine										
	Quantity	**Power, Bhp**	**Hours per Day**	**Bhp-hr**	**ROG - lb/day**	**NOx - lb/day**	**CO - lb/day**	**SOx - lb/day**	**PM10, lb/day**	**DPM, lb/day**	**GHG CO2e, MT/yr**
Off-Road Equipment											
Workover Rig	1	540	8	4,320	3.12	28.66	35.38	0.06	1.16	1.16	23.71
Cement Pump Engine	1	367	1	367							
Welding Engine	1	84	6	504							
Tractor / Backhoe / Loader	1	84	6	504							
Mud Pump Engine	1	540	8	4,320							
				10,015							

Construction Vehicle Emissions - Abandonment Per Well	Vehicle Category	Vehicle Trips	Miles per Trip	ROG - lb/day	NOx - lb/day	CO - lb/day	SOx - lb/day	PM10, lb/day	DPM, lb/day	GHG CO2e, MT/yr
Worker Pick-Up Trucks	LDA, LDT1, LDT2	20	18.5	0.09	0.10	1.51	0.00	0.02	0.02	1.25
Vendor Truck	HHDT	6	10.2	0.01	0.31	0.14	0.01	0.02	0.02	1.05
Hauling Truck	HHDT	0	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
On-Site Truck	HHDT	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				3.22	29.07	37.03	0.07	1.20	1.20	26.01

Regional Significance Threshold	75	100	550	150	150	NA	NA
Exceeds Regional Significance Threshold?	No	No	No	No	No	No	No
SCAQMD Localized Significance Threshold (@ 25m)	NA	46	231	NA	4	4	NA
Exceeds SCAQMD Localized Significance Threshold?	NA	No	No	NA	No	No	No
Number of Abandonments Per Day Before Exceed Regional Significance Threshold	3						
Number of Abandonments Per Day Before Exceed SCAQMD Localized Significance	1						

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Possible Duration for Number of Warrant E&P Wells to be Abandoned	
Idle Wells to Abandon per CalGEM Database on Wellstar	79
Active Wells to Abandon per CalGEM Database on Wellstar	165
TOTAL WELLS TO ABANDON	**244**
Weeks to Abandon One Well as one Abandonment Event	2
Wells that can be Abandoned in Two Weeks without Exceeding Regional Significance Threshold	3
Wells to Abandon Continuously in One Year without Exceeding Regional Significance Threshold	**78**
Wells that can be Abandoned in Two Weeks without Exceeding SCAQMD Localized Significance Threshold	1
Wells to Abandon Continuously in One Year without Exceeding SCAQMD Localized Significance Threshold	**26**

ATTACHMENT 3 – HEALTH RISK SCREENING OF ABANDONMENT ACTIVITIES / EXISTING MND

EMISSIONS ARE ENTERED ON THE EMISSIONS WORKSHEET OR ON ONE OF EQUIPMENT WORKSHEETS

INPUT PARAMETERS ENTERED ON THE EMISSIONS SHEET ARE USED FOR TIERS 1 AND TIER 2 ANALYSES

TIER 2 SCREENING RISK ASSESSMENT REPORT
(Procedure Version 8.1 & Package N, September 1, 2017) - Risk Tool V1.105

A/N: N/A **Fac:** Warren - Original **Application deemed complete date:** 10/12/2022

1. Stack Data

Equipment Type	Other	
Combustion Eff	0.0	
	No T-BACT	
Operation Schedule	8	hrs/day
	7	days/week
	52	weeks/year
Stack Height	14	ft
Distance to Residential	25	m
Distance to Commercial	25	m
Meteorological Station	Long Beach Airport	

2. Tier 2 Data

Dispersion Factors tables	Point Source
For Chronic X/Q	Table 6
For Acute X/Q max	Table 6.4

Dilution Factors

Receptor	X/Q (µg/m³)/(tons/yr)	X/Qmax (µg/m³)/(lbs/hr)
Residential	36.19	676.64
Commercial - Worker	36.19	676.64

Intake and Adjustment Factors

	Residential	Worker
Year of Exposure	2	
Combined Exposure Factor (CEF) - Table 4	311.35	4.47
Worker Adjustment Factor (WAF) - Table 5	1	3.00

A/N: N/A **Application deemed complete date:** 10/12/22

3. Rule 1401 Compound Data

Compound	R1 - Uncontrolled (lbs/hr)	R2 - Controlled (lbs/hr)	CP (mg/kg-day)$^{-1}$	MP MICR Resident	MP MICR Worker	MP Chronic Resident	MP Chronic Worker	REL Chronic (µg/m³)	REL 8-hr Chronic (µg/m³)	REL Acute (µg/m³)	MWAF
Particulate Emissions from Diesel-Fueled En	2.38E-02	2.38E-02	1.10E+00	1.00	1.00	1.00	1.00	5.00E+00			1

A/N: N/A

Application deemed complete date: 10/12/22

4. Emission Calculations

Compound	R1 (lbs/hr)	R2 (lbs/hr)	R1 (lbs/day)	R2 (lbs/day)	R2 (lbs/yr)	R2 (tons/yr)
Particulate Emissions from Diesel-Fueled En	2.38E-02	2.38E-02	1.90E-01	1.90E-01	6.92E+01	3.46E-02
Total	**2.38E-02**	**2.38E-02**	**1.90E-01**	**1.90E-01**	**6.92E+01**	**3.46E-02**

TIER 2 RESULTS

A/N: N/A

Application deemed complete date: 10/12/22

5a. MICR

MICR Resident = CP (mg/(kg-day))^-1 * Q (ton/yr) * (X/Q) Resident * CEF Resident * MP Resident * 1e-6 * MWAF

MICR Worker = CP (mg/(kg-day))^-1 * Q (ton/yr) * (X/Q) Worker * CEF Worker* MP Worker* WAF Worker* 1e-6 * MWAF

Compound	Residential	Commercial
Particulate Emissions from Diesel-Fueled En	4.29E-04	1.85E-05
Total	**4.29E-04**	**1.85E-05**
	FAIL	**FAIL**

5b. Is Cancer Burden Calculation Needed (MICR >1E-6)? **YES**

New X/Q at which $MICR_{70yr}$ is one-in-a-million [(µg/m³)/(tons/yr)]:	3.43E-02
New Distance, interpolated from X/Q table using New X/Q (meter):	857.15
Zone Impact Area (km²):	2.31E+00
Zone of Impact Population (7000 person/km²):	1.62E+04
Cancer Burden:	**1.71E+01**
Cancer Burden is more than 0.5	**FAIL**

6. Hazard Index Summary **A/N:** N/A **Application deemed complete date:** 10/12/22

HIA = [Q(lb/hr) * (X/Q)max * MWAF]/ Acute REL
HIC = [Q(ton/yr) * (X/Q) * MP * MWAF] / Chronic REL
HIC 8-hr= [Q(ton/yr) * (X/Q) * WAF * MWAF] / 8-hr Chronic REL

Target Organs	Acute	Chronic	8-hr Chronic	Acute Pass/Fail	Chronic Pass/Fail	8-hr Chronic Pass/Fail
Alimentary system (liver) - AL				Pass	Pass	Pass
Bones and teeth - BN				Pass	Pass	Pass
Cardiovascular system - CV				Pass	Pass	Pass
Developmental - DEV				Pass	Pass	Pass
Endocrine system - END				Pass	Pass	Pass
Eye				Pass	Pass	Pass
Hematopoietic system - HEM				Pass	Pass	Pass
Immune system - IMM				Pass	Pass	Pass
Kidney - KID				Pass	Pass	Pass
Nervous system - NS				Pass	Pass	Pass
Reproductive system - REP				Pass	Pass	Pass
Respiratory system - RESP		2.50E-01		Pass	Pass	Pass
Skin				Pass	Pass	Pass

A/N: N/A **Application deemed complete date:** 10/12/22

6a. Hazard Index Acute - Resident

HIA = [Q(lb/hr) * (X/Q)max resident * MWAF] / Acute REL

	HIA - Residential									
Compound	AL	CV	DEV	EYE	HEM	IMM	NS	REP	RESP	SKIN
Particulate Emissions from Diesel-Fueled En										
Total										

6a. Hazard Index Acute - Worker **A/N:** N/A **Application deemed complete date:** 10/12/22

HIA = [Q(lb/hr) * (X/Q)max Worker * MWAF] / Acute REL

	HIA - Commercial									
Compound	AL	CV	DEV	EYE	HEM	IMM	NS	REP	RESP	SKIN
Particulate Emissions from Diesel-Fueled En										
Total										

A/N: N/A **Application deemed complete date:** 10/12/22

6b. Hazard Index Chronic - Resident

HIC = [Q(ton/yr) * (X/Q) Resident * MP Chronic Resident * MWAF] / Chronic REL

	HIC - Residential												
Compound	AL	BN	CV	DEV	END	EYE	HEM	IMM	KID	NS	REP	RESP	SKIN
Particulate Emissions from Diesel-Fueled En												2.50E-01	
Total												2.50E-01	

A/N: N/A   Application deemed complete date: 10/12/22

6b. Hazard Index Chronic - Worker

HIC = [Q(ton/yr) * (X/Q) * MP Chronic Worker * MWAF] / Chronic REL

	HIC - Commercial												
Compound	AL	BN	CV	DEV	END	EYE	HEM	IMM	KID	NS	REP	RESP	SKIN
Particulate Emissions from Diesel-Fueled En												2.50E-01	
Total												2.50E-01	

6c. 8-hour Hazard Index Chronic - Resident **A/N:** N/A **Application deemed complete date:** 10/12/22

HIC 8-hr = [Q(ton/yr) * (X/Q) Resident * WAF Resident * MWAF] / 8-hr Chronic REI

	HIC - Residential												
Compound	AL	BN	CV	DEV	END	EYE	HEM	IMM	KID	NS	REP	RESP	SKIN
Particulate Emissions from Diesel-Fueled En													
Total													

A/N: N/A

Application deemed complete date: 10/12/22

6c. 8-hour Hazard Index Chronic - Worker

HIC 8-hr = [Q(ton/yr) * (X/Q) Worker * WAF Worker * MWAF] / 8-hr Chronic REL

	HIC - Commercial												
Compound	AL	BN	CV	DEV	END	EYE	HEM	IMM	KID	NS	REP	RESP	SKIN
Particulate Emissions from Diesel-Fueled En													
Total													

ATTACHMENT 4 – HEALTH RISK SCREENING OF ABANDONMENT ACTIVITIES / REVISED MND

EMISSIONS ARE ENTERED ON THE EMISSIONS WORKSHEET OR ON ONE OF EQUIPMENT WORKSHEETS

INPUT PARAMETERS ENTERED ON THE EMISSIONS SHEET ARE USED FOR TIERS 1 AND TIER 2 ANALYSES

TIER 2 SCREENING RISK ASSESSMENT REPORT

(Procedure Version 8.1 & Package N, September 1, 2017) - Risk Tool V1.105

A/N: N/A **Fac:** Warren - Revised **Application deemed complete date:** 10/12/2022

1. Stack Data

Equipment Type	Other	
Combustion Eff	0.0	
	No T-BACT	
Operation Schedule	8	hrs/day
	7	days/week
	52	weeks/year
Stack Height	14	ft
Distance to Residential	25	m
Distance to Commercial	25	m
Meteorological Station	Long Beach Airport	

2. Tier 2 Data

Dispersion Factors tables	Point Source
For Chronic X/Q	Table 6
For Acute X/Q max	Table 6.4

Dilution Factors

Receptor	X/Q (µg/m³)/(tons/yr)	X/Qmax (µg/m³)/(lbs/hr)
Residential	36.19	676.64
Commercial - Worker	36.19	676.64

Intake and Adjustment Factors

	Residential	Worker
Year of Exposure	2	
Combined Exposure Factor (CEF) - Table 4	311.35	4.47
Worker Adjustment Factor (WAF) - Table 5	1	3.00

A/N: N/A **Application deemed complete date:** 10/12/22

3. Rule 1401 Compound Data

Compound	R1 - Uncontrolled (lbs/hr)	R2 - Controlled (lbs/hr)	CP $(mg/kg\text{-}day)^{-1}$	MP MICR Resident	MP MICR Worker	MP Chronic Resident	MP Chronic Worker	REL Chronic (µg/m³)	REL 8-hr Chronic (µg/m³)	REL Acute (µg/m³)	MWAF
Particulate Emissions from Diesel-Fueled En	1.45E-01	1.45E-01	1.10E+00	1.00	1.00	1.00	1.00	5.00E+00			1

4. Emission Calculations

Compound	R1 (lbs/hr)	R2 (lbs/hr)	R1 (lbs/day)	R2 (lbs/day)	R2 (lbs/yr)	R2 (tons/yr)
Particulate Emissions from Diesel-Fueled En	1.45E-01	1.45E-01	1.16E+00	1.16E+00	4.23E+02	2.11E-01
Total	**1.45E-01**	**1.45E-01**	**1.16E+00**	**1.16E+00**	**4.23E+02**	**2.11E-01**

TIER 2 RESULTS

A/N: N/A **Application deemed complete date:** 10/12/22

5a. MICR

MICR Resident = CP (mg/(kg-day))^-1 * Q (ton/yr) * (X/Q) Resident * CEF Resident * MP Resident * 1e-6 * MWAF

MICR Worker = CP (mg/(kg-day))^-1 * Q (ton/yr) * (X/Q) Worker * CEF Worker* MP Worker* WAF Worker* 1e-6 * MWAF

Compound	Residential	Commercial
Particulate Emissions from Diesel-Fueled En	2.62E-03	1.13E-04
Total	**2.62E-03**	**1.13E-04**
	FAIL	**FAIL**

5b. Is Cancer Burden Calculation Needed (MICR >1E-6)? **YES**

New X/Q at which $MICR_{70yr}$ is one-in-a-million [(µg/m³)/(tons/yr)]:	5.61E-03
New Distance, interpolated from X/Q table using New X/Q (meter):	280.55
Zone Impact Area (km²):	2.47E-01
Zone of Impact Population (7000 person/km²):	1.73E+03
Cancer Burden:	**1.12E+01**
Cancer Burden is more than 0.5	**FAIL**

6. Hazard Index Summary **A/N:** N/A **Application deemed complete date:** 10/12/22

HIA = [Q(lb/hr) * (X/Q)max * MWAF]/ Acute REL
HIC = [Q(ton/yr) * (X/Q) * MP * MWAF] / Chronic REL
HIC 8-hr= [Q(ton/yr) * (X/Q) * WAF * MWAF] / 8-hr Chronic REL

Target Organs	Acute	Chronic	8-hr Chronic	Acute Pass/Fail	Chronic Pass/Fail	8-hr Chronic Pass/Fail
Alimentary system (liver) - AL				Pass	Pass	Pass
Bones and teeth - BN				Pass	Pass	Pass
Cardiovascular system - CV				Pass	Pass	Pass
Developmental - DEV				Pass	Pass	Pass
Endocrine system - END				Pass	Pass	Pass
Eye				Pass	Pass	Pass
Hematopoietic system - HEM				Pass	Pass	Pass
Immune system - IMM				Pass	Pass	Pass
Kidney - KID				Pass	Pass	Pass
Nervous system - NS				Pass	Pass	Pass
Reproductive system - REP				Pass	Pass	Pass
Respiratory system - RESP		1.53E+00		Pass	**Fail**	Pass
Skin				Pass	Pass	Pass

6a. Hazard Index Acute - Resident

HIA = [Q(lb/hr) * (X/Q)max resident * MWAF] / Acute REL

	HIA - Residential									
Compound	AL	CV	DEV	EYE	HEM	IMM	NS	REP	RESP	SKIN
Particulate Emissions from Diesel-Fueled En										
Total										

6a. Hazard Index Acute - Worker **A/N:** N/A **Application deemed complete date:** 10/12/22

HIA = [Q(lb/hr) * (X/Q)max Worker * MWAF] / Acute REL

	HIA - Commercial									
Compound	AL	CV	DEV	EYE	HEM	IMM	NS	REP	RESP	SKIN
Particulate Emissions from Diesel-Fueled En										
Total										

A/N: N/A **Application deemed complete date:** 10/12/22

6b. Hazard Index Chronic - Resident

HIC = [Q(ton/yr) * (X/Q) Resident * MP Chronic Resident * MWAF] / Chronic REL

	HIC - Residential												
Compound	AL	BN	CV	DEV	END	EYE	HEM	IMM	KID	NS	REP	RESP	SKIN
Particulate Emissions from Diesel-Fueled En												1.53E+00	
Total												**1.53E+00**	

A/N: N/A Application deemed complete date: 10/12/22

6b. Hazard Index Chronic - Worker

HIC = [Q(ton/yr) * (X/Q) * MP Chronic Worker * MWAF] / Chronic REL

	HIC - Commercial												
Compound	AL	BN	CV	DEV	END	EYE	HEM	IMM	KID	NS	REP	RESP	SKIN
Particulate Emissions from Diesel-Fueled En												1.53E+00	
Total												**1.53E+00**	

6c. 8-hour Hazard Index Chronic - Resident **A/N:** N/A **Application deemed complete date:** 10/12/22

HIC 8-hr = [Q(ton/yr) * (X/Q) Resident * WAF Resident * MWAF] / 8-hr Chronic REI

	HIC - Residential												
Compound	AL	BN	CV	DEV	END	EYE	HEM	IMM	KID	NS	REP	RESP	SKIN
Particulate Emissions from Diesel-Fueled En													
Total													

A/N: N/A **Application deemed complete date:** 10/12/22

6c. 8-hour Hazard Index Chronic - Worker

HIC 8-hr = [Q(ton/yr) * (X/Q) Worker * WAF Worker * MWAF] / 8-hr Chronic REL

	HIC - Commercial												
Compound	AL	BN	CV	DEV	END	EYE	HEM	IMM	KID	NS	REP	RESP	SKIN
Particulate Emissions from Diesel-Fueled En													
Total													

ATTACHMENT B

Warren RESOURCES

Green Hill Towers
14131 Midway Rd., Suite 500
Addison, Texas 75001
Office: (214) 393-9688

September 19, 2022

VIA EMAIL: CPC@LACITY.ORG

Los Angeles City Planning Commission
200 N. Spring Street, Room 525
Los Angeles, CA 90012

Re: **Agenda Item #11 - CPC-2022-4864-CA; Council File No. 17-0447**
Warren Comment Letter Opposing Ordinance Amendment and Approval of MND

Dear President Millman and Honorable Commissioners:

This letter provides comments on behalf of Warren E&P, Inc.; Warren Resources of California, Inc.; Warren Resources, Inc.; Warren Management Corp.; and Warren Operating LLC (collectively "Warren") opposing the ordinance amending Sections 12.03, 12.20, 12.23, 12.24, and 13.01 of the Los Angeles Municipal Code (LAMC) to prohibit new oil and gas drilling activities and make existing extraction a noncomforming use in all zones (the "Ordinance Amendment"). While the comment period is still pending for the associated proposed Mitigated Negative Declaration ENV-2022-4865-MND ("MND"), the Commission is being asked to recommend the City Council approve the same and thus, Warren also objects to that action, especially since the Commission does not have the benefit of all comments on that proposed action since they are not due until October 17, 2022. In addition to the comments in this letter, Warren incorporates the comments of other industry organizations and companies that were submitted in connection with the August 30, 2022 Planning Staff Meeting in opposition to the Ordinance Amendment (as attached to the Staff Recommendation Report) and any additional comments that are submitted by other industry organizations and companies in connection with the upcoming September 22, 2022 Planning Commission Meeting.

The Ordinance Amendment Effects an Unconstitutional Taking for Which Just Compensation Must Be Paid & Deprives Warren of Its Vested Rights

At the outset, please understand that the Ordinance Amendment, if adopted in its current form, will put Warren out of business in approximately three years, depriving Warren—and the royalty owners that it serves—of their real property rights. These rights are currently valued in excess of $675MM and the U.S. and California Constitutions require the City to compensate Warren and its mineral owners for these losses. The Ordinance Amendment, however, unlawfully makes no provision for such compensation.

The Ordinance Amendment will result in cessation of Warren's existing production in approximately three years because it prohibits Warren from engaging in the customary operations necessary to maintain production from its existing wells. Warren's only operations and its only mineral rights are located within the City of Los Angeles and new wells are prohibited. As a result, the Ordinance Amendment would unquestionably put Warren out of business after three years, leaving its employees jobless, their families without necessary financial support and its royalty owners without income that they have relied on for decades.

To date, Warren has invested over $400MM to develop its mineral estate in the City of Los Angeles through three well cellars at a consolidated drilling facility (the "Site"). The current LAMC allows for these operations as a *permitted right*. Warren's investment of over $400MM was incurred not merely for its existing production at the Site but also for additional operations on existing wells within the three well cellars, so that production can be maintained over the projected life of the wells, and for the drilling of new wells in the same three cellars. The Ordinance Amendment will affect a zoning change that deprives Warren of engaging in its business at the Site and its business as a whole, subjecting the City's action to heightened scrutiny under the independent judgment standard. (*See e.g., Goat Hill Tavern v. City of Costa Mesa* (1992) 6 Cal.App.4th 1519, 1525.)

Warren and its royalty owners will be deprived of their reasonable investment-backed expectations and of the right to develop the remaining reserves, which are presently valued in excess of $675MM. The Ordinance Amendment thus will result in a taking of Warren's and its royalty owner's real property rights under the U.S. and California Constitutions, thereby subjecting the City to damages for this lost value—a significant liability for the taxpayers of the City of Los Angeles. (*See e.g., Penn Cent. Transp. Co. v New York City* (1978) 438 U.S. 104; *Hansen Brothers Enterprises v. Board of Supervisors* (1996) 12 Cal.4th 533, 553-554 (holding that "absolute prohibition [on mining] . . . practically amounts to a taking of the property").)

Even though it holds mineral rights in other residential areas of the City, Warren limited its operations to the Site and to the three well cellars at the City's specific request. Also at the City's specific request, Warren agreed to give up its right to redrill 560 wells located outside the Site and agreed to a phased process of plugging and abandoning wells in the nearby area in return for the City agreeing that Warren could drill 540 wells at the Site with up to 5 well cellars.[1][2] To date, Warren has plugged and abandoned 41 wells in the surrounding area and has plans to plug and abandon more wells as its business continues to operate in the City.

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[1] Zoning Case ZA 20725-0 (PA1) dated July 20, 2006 and Zoning Case ZA 20725-0 (PA2) dated October 2, 2008 (the "Approvals"), copies of which are not attached hereto due to the 10-page limit for this submission but can be found in the Planning Department records.

[2] Warren was not required under the LAMC relating to the Approvals to give up the redrill rights to 560 wells and conduct the plugging and abandonment of 56 wells in the residential areas outside the Site within a certain time period. Neither were these measures related to the mitigation of environmental impacts. Accordingly, there was no essential nexus and rough proportionality as would be required if the Approvals were interpreted solely as permits under *Nollan v. California Coastal Comm'n,* 483 U.S. 825 (1987) and *Dolan v. City of Tigard,* 512 U.S. 374 (1994). Accordingly, the Approvals constituted a contractual obligation and give rise to a vested property right for that and other reasons. (*See M. J. Brock & Sons, Inc. v. City of Davis,* 401 F.Supp. 354, 361 (1983); *Morrison Homes Corp. v. City of Pleasanton.* 58 Cal.App.3d 724 (1976).) The Ordinance Amendment thus would improperly deny Warren a vested property right in violation of due process of law.

If the Ordinance Amendment is adopted, Warren will not be allowed to complete its project under the terms agreed upon by the City since no new wells will be allowed (221 wells have been drilled to date) and existing production cannot be maintained. Warren, however, has a legally protected and vested property right to utilize the Site for these additional operations. (*See e.g., Avco Community Developers, Inc. v. South Coast Regional Com.* (1976) 17 Cal. 3d 785, 791.)

The *Avco* rule provides that when a property owner has performed substantial work and incurred substantial liabilities in good faith reliance upon an entitlement issued by an agency, the party acquires a vested right to complete the construction of the project. This is particularly true for Warren in that not only did Warren obtain all necessary approvals from the City, but it also gave up its rights to redrill 560 wells in the Wilmington neighborhood outside the Site. Accordingly, Warren must be allowed to complete its project.

Warren's situation is similar to that presented in the case *Goat Hill Tavern v. City of Costa Mesa* (1992) 6 Cal.App.4th 1519, 1530. In that case, as in Warren's, the owner had an underlying right to use the property as a tavern. The owner subsequently obtained a conditional use permit to expand the business. When that permit expired, the City argued that the owner's rights had expired. However, the *Goat Hill Tavern* court held that "once [an approval] has been properly issued the power of a municipality to revoke it is limited . . . Where [an approval] has been properly obtained and in reliance thereon the [grantee] has incurred material expense, he acquires a vested property right to the protection of which he is entitled." (*Goat Hill Tavern*, 6 Cal.App.4th at 1530.)

Similar to *Goat Hill Tavern,* where the tavern owner had an underlying nonconforming use right, Warren also has a right to use the Site as an oil and gas well drilling site by virtue of the City's February 25, 1972 approval of a drilling and production site within the Nonurbanized Oil Drilling District No. 5 in the R4 and M2-1-O zones and by virtue of the Approvals. The *Goat Hill Tavern* court cited to multiple cases in which an agency action would ultimately force the company out of business, which as discussed above is what will happen here with Warren. (*Id.* at 1528-1529.) The court also emphasized that "interference with the right to continue an established business is far more serious than when an agency denies a request for a permit in the first instance." (*Id.* at 1529.) Once a permittee has acquired such a vested right it may be revoked only if the permittee "fails to comply with *reasonable* terms or conditions *expressed* in the permit granted." (*Id.* at 1530 (emphasis added).) Here, the Ordinance Amendment completely revokes Warren's vested rights despite its compliance with terms and conditions expressed in the 1972 approval of the "O" drilling district and in the Approvals, and thus Warren will be deprived of its vested real property rights.

That the City's actions will extinguish Warren's business is readily ascertainable in that Warren must either continuously drill and maintain its wells, or go out of business. The California Supreme Court recognized in *Hansen Brothers Enterprises v. Board of Supervisors* (1996) 12 Cal.4th 533 that unlike other uses that operate within an existing structure or boundary, the use of land for mining and, in this instance, oil and gas drilling, anticipates the need to continuously expand the reach of the extraction activity. Warren must drill new wells and redrill and maintain old wells on the Site to maintain its current business. As stated by the California Supreme Court in *Hansen Brothers,* "this is not the usual case of a business conducted within buildings, nor is the land held merely as a site or location whereon the enterprise can be conducted indefinitely with existing facilities. . . the land itself is a material resource. It constitutes a diminishing asset." *Id.* at 553-554. Accordingly, "the ordinary concept of use must yield to the realities of the business in question and nature of its operations." *Id.* Given Warren's substantial economic investment, Warren's drilling rights are a vested property right and if the City chooses to terminate these rights, Warren would be entitled to compensation under the California and United States constitutions.

Consideration of the Amended Ordinance Now Violates the City's Own Procedural Requirements Such that It Would Be Unlawful to Adopt the Recommended Findings

The relevant City procedures for consideration of the Amended Ordinance are set out at Los Angeles Charter and Administrative Code ("LACAC") Sections 556 and 558. These requirements are further described in the Staff Recommendation Report at the Proposed Findings 1-3 at ps. F-1 to F-6, which Findings the Planning Commission must adopt to recommend adoption of the Amended Ordinance to the City Council.

LACAC Section 558(b)(2) describes the procedures for amending an ordinance. It provides that "[a]fter initiation, the proposed ordinance . . . shall be referred to the City Planning Commission for its report and recommendation regarding the relation of the proposed ordinance . . . to the General Plan and, in the case of proposed zoning regulations, whether adoption of the proposed ordinance . . . will be in conformity with public necessity, convenience, general welfare and good zoning practice."

LACAC Section 556 provides that: "when approving any matter listed in Section 558, the City Planning Commission and the Council shall make findings showing that the action is in substantial conformance with the purposes, intent and provisions of the General Plan."

The Planning Commission's action is not a mere suggestion, but acts to set out how the City Council must proceed in potentially acting on the Ordinance Amendment and the MND. For example, if the Planning Commission recommends approval of the Ordinance Amendment and the MND, the City Council may approve it under a simple majority vote, while if the Planning Commission has recommended against the Ordinance Amendment and the MND, the City Council can only approve the change by a two-thirds vote. (LACAC § 558(b)(3).) Accordingly, the Planning Commission's action on the Amended Ordinance must be in compliance with applicable laws and meet the standards of Sections 556 and 558 of the LACAC.

The Planning Commission Cannot Lawfully Take Action Until It Completes its Review under CEQA

The Planning Commission may not vote to recommend the Amended Ordinance until the City completes the CEQA process. In this situation, the proposed MND was only just circulated to the public on September 15, 2022—four days ago—in conjunction with the issuance of the Staff Recommendation Report. The City states that the public comment period will extend through October 17, 2022, as is required by CEQA. Accordingly, the City has not yet received all comments from the public on the proposed MND and indeed, it would be a denial of due process and violation of CEQA to expect comments in such a short period of time.

Yet at the same time the Planning Commission is being asked to recommend that the City Council find that "after consideration of the whole of the administrative record, including the Mitigated Negative Declaration . . . *and all comments received*, with the imposition of mitigation measures, there is no substantial evidence that the project will have a significant effect on the environment." (Staff Recommendation Report at p. 1-2, and at p. A-8 (emphasis added).)

The Planning Commission is also being asked to adopt Proposed Finding 3, which states that the City has prepared an MND for the project and that "[i]n consideration of the whole administrative record *and all comments received regarding the MND* . . . the City Planning Commission shall recommend the City Council to adopt the MND." (Staff Recommendation Report, Proposed Finding 3 at p. F-6.)

Proposed Finding 2 also clearly requires the completion of the CEQA review. Proposed Finding 2, which the Planning Commission must make pursuant to LACAC Section 556 provides that "[i]n accordance with City Charter Section 558 (b)(2), the proposed ordinance will be in conformance with public necessity, convenience, general welfare, and good zoning practice by advancing the basic core zoning to project citizens' health, safety, and welfare." Impacts to the public's general welfare including its health and safety, however, are evaluated through the CEQA review, which process has not been completed and the comment period is still pending.

Accordingly, pursuant to LACAC Sections 556 and 558 and Proposed Finding 2 and 3, the Planning Commission must complete the CEQA process, including completion of the public comment period, prior to taking action to recommend adoption of the MND and adoption of the Amended Ordinance by the City Council.

Even without these explicit requirements, the proposed action would violate CEQA. Amendments to ordinances are clearly a project under CEQA. The completion of the CEQA process, including the required comment period and the consideration of these comments, is necessary as to two fundamental purposes of CEQA, informed decision making *by the agency* and informed public participation. The case law is clear that the failure to satisfy these requirements is prejudicial error. (*County of Amador v. El Dorado County Water Agency* (1999) 76 Cal.App.4th 931, 946.)

The California Supreme Court has explicitly rejected what the Planning Commission is being asked to do—take an action prior to the completion of CEQA review. In particular, in *Laurel Heights Improvement Assn. v. Regents of University of California* (1988) 47 Cal.3d 388, 394 the Supreme Court stated that:

> A fundamental purpose of [a CEQA document] is to provide decision makers with information they can use in deciding whether to approve a proposed project, not to inform them of the environmental effects of projects that they have already approved. If post approval environmental review were allowed, [CEQA documents] would likely become nothing more than post hoc rationalizations to support action already taken. We have expressly condemned this.

Accordingly, under not only its own requirements under CACAC Sections 556 and 558 and under the language proposed in the recommended actions and Proposed Findings, but also under basic CEQA law, the Planning Commission cannot act on the recommendation until the CEQA process is complete. Otherwise, the Planning Commission will deprive the public of the right to participate in the process and prevent itself from engaging in informed decision making.

A Brief Review of the MND Indicates That the City Must Prepare an EIR for the Proposed Project

A brief review of the MND (it was only published four days ago) indicates that the Planning Department has understated the impacts that will result from this project. It is clear that, ultimately, the City will be required to prepare an EIR.

The MND's analysis of greenhouse gas emissions ("GHGs") is clearly deficient because it only analyzes the direct impacts related to curtailing oil and gas production in the City. It does not analyze any indirect impacts related to the termination of oil and gas production, which it is required to do under CEQA. (CEQA Guidelines Section 15064(d).) For example, the MND does not discuss that the termination of oil and gas extraction and production activities will result in additional imports of oil to the State and region, and that importation will result in additional GHGs through, for example, additional tanker emissions.

The MND also is required to discuss the consistency of the Ordinance Amendment with City land use policies. As they did with the Proposed Findings, the MND fails to address multiple policies that support the extraction and production of oil within the City (as discussed above).

Further, the MND glosses over the impacts to mineral resources in determining that the impacts related to the Ordinance Amendment are insignificant. As described above, the MND omits critical information from the General Plan related to the encouragement of extraction to reduce dependency on oil imports. The MND's remarks that the City "does not consider petroleum to be a mineral resource of local importance" is thus not supported by the City's own General Plan. Moreover, the CEQA Guidelines require the City to evaluate "the loss of availability of a known mineral resource that would be of value to the region and the residents of the state" not just the City. Accordingly, the analysis is flawed in that it addresses only impacts to the City, not the State as a whole.

The MND's conclusion that oil produced in the area "represents a small amount of the available Statewide resource" is also contradicted by readily available public information. For example, a report by the US Geological Service dated February 2013 describes the Los Angeles Basin, which is partly encompassed by the City, as containing "one of the highest concentrations of crude oil in the world. Sixty-eight oil fields have been named . . . including 10 accumulations that each contain more than 1 billion barrels of oil. One of these, the Wilmington-Belmont, is the fourth largest oil field in the United States." (USGS Fact Sheet 2012-3120.) Accordingly, based on this expert evidence it is undeniable, that the proposed ordinance will have a significant impact on the availability of mineral resources. Based on this information alone, the City is required to develop an EIR. CEQA requires that where there is substantial evidence supporting a fair argument that the project could have a significant non-mitigable effect the City must prepare an EIR. (CEQA Guidelines Section 15064(f)(1).) Even where there is "disagreement among expert opinion supported by the facts over the significance of an effect on the environment, the Lead Agency shall treat the effect as significant and shall prepare an EIR." (CEQA Guidelines Section 15064(g).)

The City's General Plan Review For Conformity is Incomplete and Thus Unlawful

At noted above, CACAC Section 556 provides that the Planning Commission must find that proposed ordinance is in conformity with the General Plan. Such consistency is required by law. (*See e.g., City of Los Angeles v. State of California* (1982) 138 Cal.App.3d 526, 532.) This consistency is also required for charter cities pursuant to Government Code Section 65860. As discussed below, the ***Ordinance Amendment is not consistent with the City's General Plan.***

The Staff Recommendation Report at Proposed Finding 1 leaves out critical elements in the General Plan in concluding that the Ordinance Amendment is in conformance with the purposes and intent of the General Plan. For example, in discussing the Conservation Element of the General Plan, Proposed Finding 1 sets out three policies. These policies generally describe a need for encouraging energy conservation, supporting the ban on offshore drilling and protecting neighborhoods from potential accidents and subsidence associated with drilling and production.

However, listed directly above these policies, and not stated in Finding 1, is the "Objective" that these policies support. In particular, the objective is to: "conserve petroleum resources and *enable appropriate, environmentally sensitive extraction* . . . so as to protect the petroleum resources for the use of future generations and to reduce the city's dependency on imported petroleum and petroleum products." (Emphasis added.) Accordingly, these policies may only be read in the context of allowing continued extraction. The fact that the Amended Ordinance would *ban extraction* rather than *enable extraction* clearly means that it is inconsistent with the General Plan.

Similarly, in the Health Wellness and Equity Element to the General Plan, Finding 3 indicates that Policy 5.4 is to protect communities' health from noxious activities (which Finding 3 states includes, for example, oil and gas extraction). However, not included in the Staff Recommendation Report is that: "[t]his policy calls for the City to work with operators to ensure that they have the required permits in place, increase its regulatory role and encourage conditions of approval that mitigate land use inconsistencies and conflicts." As a result, this section also assumes the continuance of extractions activities within the City.

Similarly, a brief review of the Land Use Element – Wilmington Harbor City Community Plan likewise indicates that the Amended Ordinance is inconsistent with the Wilmington Harbor City Community Plan. For example, Policies 3-5.1 and 3.5.3 clearly contemplate the continuance of extraction activities. Policy 3-5.4 provides for the consolidation of oil extraction operations to increase compatibility between oil activities and other land uses. Accordingly, nothing in these policies is consistent with a total ban on oil production like that proposed in the Ordinance Amendment. Finding 1 also does not discuss Objective 3-5, which the policies are drafted to support and which provides that the objective of the policies is "[t]o ensure the public health, safety and welfare *while providing for reasonable utilization* of the area's oil and gas resources." (Emphasis added.) The Staff Recommendation Report also fails to note Policy 3-4.6, which encourages the *consolidation* of oil extraction activities rather than its *elimination.*

Accordingly, not only is the Ordinance Amendment inconsistent with the General Plan and thus unlawful, but the Staff Recommendation Report omits critical information necessary for Planning Commission and public review of the Ordinance Amendment.

The Ordinance Amendment is Unconstitutionally Vague and Ambiguous

The Ordinance Amendment provides that "[no] existing well . . . shall be "*maintained*, drilled, re-drilled, or deepened, except to prevent or respond to a threat to public health, safety, or the environment, as determined by the Zoning Administrator." (Emphasis added.) The Ordinance Amendment, however, provides no definition of the word "maintained" and it is thus unconstitutionally vague and ambiguous and violates the due process clause of the U.S. Constitution. The Staff Recommendation Report acknowledges that this is a problem and defers to a "Zoning Administrator's Interpretation" that has not yet been published as to what this term means. (Staff Recommendation Report, P.3 ("Separately from this Ordinance, DCP's Office of Zoning Administration is preparing a Zoning Administrator's Interpretation on the types of oil-related activities that constitute maintenance . . . Once final, this guidance would immediately apply to all oil drilling activities. It would further clarify the types of maintenance activities prohibited under the Ordinance, with limited exceptions to prevent or respond to threats to public health, safety, or the environment.")

Due process requires fair notice and an opportunity to be heard. In turn, the most basic due process concepts require that legally enforceable ordinances be defined with sufficient clarity such that those subjected to the laws understand what is permitted and what is prohibited, and such that the laws are not susceptible to arbitrary or discriminatory enforcement. (*Genis v. Bell (C.D. Cal. July 2, 2013) 2013 U.S. Dist. LEXIS 93353,* *14-15; *see also Castro v. Terhune*, 712 F.3d 1304, 1307 (9th Cir. 2013).) Here, the failure to unambiguously explain what is meant by the word "maintained" in the Ordinance Amendment itself would mean that Warren and others similarly situated would not know when, if at all, it is violating the Ordinance Amendment. As written without any definition, Warren is deprived of advance notice and opportunity to object to the meaning of the term "maintained" since it is left to later interpretation by the Zoning Administrator.

The 20-Year Amortization Period in the Ordinance Amendment is Unlawful

The Ordinance Amendment unlawfully imposes a 20-year amortization period for existing operations without any factual evidence to support that 20 years is a "reasonable amortization period commensurate with the investment involved," as required by law. (*Metromedia, Inc. v. San Diego* (1980) 26 Cal.3d 848, 882.) The City Council directed the Planning Department to commission a study to be performed as to an appropriate amortization period and that work has not yet even commenced, let alone been completed. It thus is premature and unlawful for the Planning Commission to proceed with taking action on an amortization period when there is no study—and no evidence—to support such a period for Warren or other operators within the City.

Moreover, there is no law in California to support the use of amortization periods to eliminate a diminishing asset like mineral rights. While amortization may be appropriate under certain factual situations involving movable property like billboards or liquor stores, since those uses can be moved to other locations, the development of mineral rights is immovable and, as discussed above, protected under the diminishing asset doctrine. There is no way to equitably amortize Warren's real property rights and its investments therein other than to allow Warren to produce until the commercially recoverable resources are depleted.

There is No Evidence to Support that Warren's Operations Result in Negative Health Effects

Warren not only complies with California's stringent environmental regulations, but it also agreed with the City to use electric sources for its operations except for two combustion sources which produce minimal emissions and are not a significant impact for the City. The Staff Recommendation Report contains no specific evidence as to Warren's operations or its emissions and also ignores the City's prior report that failed to support any negative health impacts from oil and gas operations within the City.

In 2019, the City of Los Angeles Office of Petroleum and Natural Gas Administration and Safety conducted an exhaustive review of government reports and studies and concluded that:

> There is a lack of empirical evidence correlating oil and gas operations within the City of Los Angeles to widespread negative health impacts. The lack of evidence of public health impacts from oil and natural gas operations has been demonstrated locally in multiple studies by the Los Angeles County Department of Public Health, the Los Angeles County Oil & Gas Strike Team, the South Coast Air Quality Management District and the comprehensive Kern County Environmental Impact Report and Health Risk Assessment.

The City's position now is contrary to that prior report and not supported by the evidence. Warren's equipment and operations do not emit significant quantities of air pollutants and do not pose a significant health risk to the community residents or the public. Warren participates in annual emissions reporting to the SCAQMD, which includes mandatory reporting of air pollutants regulated by the Clean Air Act. Warren facility's actual emissions are low and based on these reported emissions the facility has never been required to obtain a federal operating air permit as it remains below major source thresholds for all pollutants. Further, low emissions of regulated pollutants is evidenced by the fact that Warren does not participate in the SCAQMD's RECLAIM program for large sources of oxides of nitrogen (NOx) and sulfur (SOx). Lastly, as a minor stationary source located in a heavily industrialized area of Wilmington, Warren has not permitted or installed new equipment or modified existing equipment in over 6 years.

In addition to regulated pollutants, Warren has consistently reported low emissions of air contaminants. The facility routinely reports a detailed air toxics emissions inventory to the SCAQMD yet has never been required by the SCAQMD to prepare a Health Risk Assessment (HRA) because of low emissions. For example, Warren's reported emission of air pollutants and associated health risk impacts are on par with that of neighborhood gas station that operates fuel dispensing equipment, storage tanks, and vehicular traffic from customers and mobile tankers.

Warren is in compliance with all regional, state, and federal rules and regulations and has obtained the appropriate air quality permits for all operating equipment. Restricting maintenance, testing, and repair of the existing equipment would not represent an emission reduction or result in any improved air quality for the area or the region.

Furthermore, and in violation of the Equal Protection Clause as applied through the Fourteenth Amendment to the U.S. Constitution, the City is unlawfully discriminating against one industry by prohibiting its operations within the City without taking similar actions against other industries or uses that provide similar or even more emissions than the oil and gas industry.

No Action Should Be Taken on the Ordinance Amendment and the MND

Warren respectfully requests that the Planning Commission do everything within its power to avoid what will prove to be an expensive mistake and we urge you ***not*** to take action on Agenda Item No. 11. The Ordinance Amendment will not result in the professed health benefits from shutting down Warren's operations and, instead, will subject the City to significant liability.

It is even premature for the Planning Commission to consider the draft MND and the Ordinance Amendment at this time. Indeed, the comment period has just began to run on the draft MND so the rush to take action should heed to the Commission's obligations to comply with the law and the City's ordinances.

Please understand that if the Planning Commission recommends approval, Warren will take all actions required to protect its rights, including seeking recovery from the City of in excess of $675MM in damages for putting Warren out of business, along with recovery of Warren's legal expenses under Code of Civil Procedure Sections 1021.5 and 1036. The City will be forced to incur substantial legal fees for its own counsel and ultimately Warren's counsel too, all the while losing significant revenue from property taxes on future oil and gas operations without any change in health impacts from closing Warren's doors. Warren reserves all of its rights to pursue every available remedy if the Planning Commission proceeds to recommend approval of the Ordinance Amendment and the draft MND to the City Council.

Sincerely,

WARREN RESOURCES, INC.

James A. Watt
President and Chief Executive Officer

Communication from Public

Name:	Elizabeth Jones
Date Submitted:	11/21/2022 03:38 PM
Council File No:	17-0447-S2
Comments for Public Posting:	In response to oil industry comments that drilling operations do not negatively impact public health and the environment, the Center for Biological Diversity offers the following list of studies and articles. There is strong evidentiary support for the City's action. Select studies have been submitted as attachments. This is submission 1 of 2 to stay below file size requirements.

HEALTH STUDIES AND REPORTS THAT SUPPORT LOS ANGELES CITY'S ORDINANCE TO PROHIBIT NEW OIL AND GAS EXTRACTION AND MAKE EXISTING EXTRACTION ACTIVITIES A NONCONFORMING USE IN ALL ZONES

In response to oil industry comments that drilling operations do not negatively impact public health and the environment, the Center for Biological Diversity offers the following list of studies and articles. There is strong evidentiary support for the City's action. Select studies mentioned below have been submitted as attachments.

- A substantial body of national and California-based scientific research documents the deleterious health impacts of living, working, and playing in close proximity to oil drilling operations, including asthma and other respiratory illnesses, headaches, rashes, cardiovascular disease, nausea, nosebleeds, reproductive harm, and some types of cancer.
  - Oil and Gas Extraction in Los Angeles and Public Health Evidence by scientists and healthcare professionals (2019)
  - Human Health and Oil and Gas Development in the City of Los Angeles by Physicians, Scientists, and Engineers (PSE) for Healthy Energy (2019)
  - The Public Health Dimensions of Oil and Gas Development in California by PSE Healthy Energy (2017)
  - Public Health and Safety Risks of Oil and Gas Drilling in Los Angeles by LA County Department of Public Health (2018)
  - Danger Next Door: The Top 12 Air Toxics Used for Neighborhood Oil Drilling in Los Angeles by Center for Biological Diversity (2017)
  - Air Pollution Is Slashing Off the Lives of Billions news article (2021)
  - Harvard Study Links Fossil Fuels to Millions of Premature Deaths news article (2021)
- Scientific research published in 2020 documents harmful reproductive impacts from oil and gas in California, specifically, evidence of low birth weight infants and pre-term births.
  - Residential Proximity to Oil and Gas Development and Birth Outcomes in California: A Retrospective Cohort Study of 2006–2015 Births (News article) by University of California researchers in Environmental Health Perspectives (2020)
  - Oil and gas production and spontaneous preterm birth in the San Joaquin Valley, CA (News article) by Stanford University researchers in Environmental Epidemiology (2020)
- Recent scientific research documents significant decreased lung and pulmonary function from living close to drill sites in South Los Angeles.
  - Respiratory health, pulmonary function and local engagement in urban communities near oil development (News article) by Johnston et al. in Environmental Research (2021). This 2021 study near the Jefferson and Allenco drill sites found that individuals living downwind and closer than 200 m to both idle and active wells had significantly lower lung functioning than those living upwind and further than 200 m away. These impacts were more pronounced in communities near active wells. In addition, individuals near active wells self-reported more acute symptoms of exposure including chest tightness, wheezing, and eye irritation compared to those near idle wells. The study found significant correlation between living near both active and idle oil and gas wells and reduced lung function.
  - Community-Based Health and Exposure Study around Urban Oil Developments in South Los Angeles by Shamasunder et al. in International Journal of Environmental Research and Public Health (2018). An earlier 2018 also focused on the Las Cienegas Oil Field and found that individuals in the University Park and West Adams neighborhoods of Los Angeles had diagnosed

asthma rates significantly higher than California's overall rates, while the West Adams neighborhood has rates significantly higher than LA County.

- The California Oil and Gas Public Health Rulemaking Scientific Advisory Panel was assembled in 2021 to advise the California Geologic Energy Management Division. The Panel found that there is a high level of certainty that living in proximity to oil and gas wells is associated with negative respiratory and perinatal health impacts. The Panel also noted how studies consistently show negative health impacts at distances less than 1 km from oil and gas wells, and some show harm at distances greater than 1 km from wells. Further, the Panel concluded with a high level of certainty that concentrations of health-damaging air pollutants, including criteria air pollutants and toxic air contaminants, are more concentrated near oil and gas activities compared to further away. The Panel recommended reducing or eliminating oil and gas wells as the most effective method in mitigating local and regional environmental hazards due to oil and gas development.
- Researchers in California have also completed studies to better understand how oil and gas operations contribute to air pollution and distinguish oil-related pollution in neighborhoods near wells.
  - Upstream oil and gas production and ambient air pollution in California by Gonzalez et al. in Science of the Total Environment (2022)
  - Using gas-phase air quality sensors to disentangle potential sources in a Los Angeles neighborhood by Collier-Oxandale et al. in Atmospheric Environment (2020)
  - Characterizing methane and total non-methane hydrocarbon levels in Los Angeles communities with oil and gas facilities using air quality monitors by Okhorn et al. In Science of the Total Environment (2021)

CLIMATE IMPACTS

"Oil and gas facilities emit large quantities of methane, a potent climate change pollutant. Climate change already impacts the health of millions of Americans, from extreme heat, increased air pollution, worsened wildfires, and more." (American Lung Association, 2019)

- Methane 80 times more potent a greenhouse gas than carbon dioxide in the short term
- Oil and gas facilities also emit highly reactive pollutants called volatile organic compounds (VOCs) that can cause cancer and other harmful health impacts. VOCs react with other pollutants to form ozone pollution

In 2021, the Intergovernmental Panel on Climate Change (IPCC) issued the Working Group 1 report, which made many findings underscoring that the climate crisis has reached a "code red for humanity."

- Climate change is widespread, intensifying and many changes are unprecedented in thousands of years of Earth history
- It's "unequivocal" that humans are warming the world – and at a rate faster than anything during at least the past 2,000 years
- The last decade's global temperatures were likely the hottest it's been on Earth in 125,000 years.
- The recent rate of sea level rise has nearly tripled compared with 1901-1971
- Carbon dioxide emissions in 2019 were higher than any time in at least 2 million years
- We can still prevent the worst damages of the climate crisis (limiting warming to 1.5), but we must act now. We need immediate transformative change from our federal and state governments to end new fossil fuel projects, phase-out existing fossil fuel extraction and use, and speed a just transition to clean, renewable energy.
- The UN Secretary General has said that the report "must sound a death knell for coal and fossil fuels, before they destroy our planet."

Studies show that limiting oil production would help California meet its climate goals, particularly given the high—and rapidly increasing—greenhouse gas emissions intensity of oil and gas production in California.

- How limiting oil production could help California meet its climate goals by Stockholm Environment Institute (2018)
- Killer Crude: How California Produces Some of the Dirtiest, Most Dangerous Oil in the World, by Center for Biological Diversity (2021)

ENVIRONMENTAL JUSTICE IMPACTS

- 72 percent of people living near oil and gas drilling in Los Angeles County are people of color. (Table from Drilling Down by Liberty Hill Foundation (2015))

Demographic Characteristics in Selected Areas Hosting Oil Production Facilities

LOCATION	PEOPLE OF COLOR	200% POVERTY	RENTERS	LINGUISTI-CALLY ISOLATED	LESS THAN HIGH SCHOOL EDUCATION
L.A. County	72.6%	37.3%	46.9%	12.4%	27.0%
L.A. City	72.9%	44.5%	56.2%	18.7%	30.8%
Within 1,500 ft. of an active L.A. City well	74.4%	42.3%	55.7%	18.5%	30.3%
University Park: Allenco	87.0%	72.6%	90.6%	50.0%	42.5%
Historic West Adams: Jefferson	83.4%	73.5%	70.9%	27.0%	48.5%
Historic West Adams: Murphy	89.7%	60.2%	73.4%	21.8%	35.5%
Wilmington: Warren E&P	99.7%	53.6%	76.6%	42.4%	54.3%
Baldwin Hills: Inglewood Oil Field	78.8%	45.2%	34.9%	2.0%	30.1%

Analysis by authors using the 2010 US Census.

- Studies make clear that Latinx, Black, Indigenous, other people of color are hardest hit by the negative environmental impacts exacerbated by climate change:
  - Racial Disparities and Climate Change by PSCI (2020)
  - Urban Heat Management and the Legacy of Redlining by Bev Wilson in Journal of the American Planning Association (2020)
  - Drilling in California: Who's at Risk? by Natural Resources Defense Council (2014)

OTHER RELEVANT STUDIES AND REPORTS

- Polling: Californian's Overwhelmingly Want Action on Oil Hazards, Just Transition by Change Research (2020)
- Study of Neighborhood Air near Petroleum Sources by California Air Resources Board
- Orphan Wells in California by California Council on Science and Technology (2020)
- An Oil and Gas Setback in Los Angeles Would Not Create Billions in Liability by UCLA law professors in Legal Planet (2019)
- Urban Oil and Gas Production in LA County by University of Southern California Environmental Health Centers (2019)
- It's Time to Stop Urban Oil Drilling in Los Angeles by Kyle Ferrar, Fractracker (2021)

Exhibit 1 of 13 - CalGEM Public Health Panel 2021_Panel Responses

David Shabazian, Director
Uduak-Joe Ntuk, California State Oil and Gas Supervisor
California Department of Conservation
801 K Street, MS 24-01
Sacramento, CA 95814

October 1, 2021

RE: Response to CalGEM Questions for the California Oil and Gas Public Health Rulemaking Scientific Advisory Panel

Director Shabazian and Supervisor Ntuk,

Please find attached the responses from the California Oil and Gas Public Health Rulemaking Scientific Advisory Panel to the written questions sent by the California Geologic Energy Management Division (CalGEM) on August 31, 2021.

We would be glad to answer any further questions that may arise.

Best Regards,

Seth B.C. Shonkoff, PhD, MPH
Co-Chair, California Oil and Gas Public Health Rulemaking Scientific Advisory Panel
Executive Director, PSE Healthy Energy
Visiting Scholar, Department of Environmental Science, Policy, and Management, University of California, Berkeley
Affiliate, Energy Technologies Area, Lawrence Berkeley National Lab

Rachel Morello-Frosch, PhD, MPH
Co-Chair, California Oil and Gas Public Health Rulemaking Scientific Advisory Panel
Professor, Department of Environmental Science, Policy and Management & School of Public Health, University of California, Berkeley, Berkeley CA

Joan A. Casey, PhD, MA
Assistant Professor, Department of Environmental Health Sciences, Columbia University Mailman School of Public Health, New York, New York

Nicole Deziel, PhD, MHS
Associate Professor, Department of Environmental Health Sciences, Yale School of Public Health, Yale University, New Haven, Connecticut

Dominic C. DiGiulio, PhD, MS
Senior Research Scientist, PSE Healthy Energy
Affiliate, Department of Civil, Environmental, and Architectural Engineering, University of Colorado, Boulder

Stephen Foster, PhD
Senior Principal, Geosyntec Consultants

Robert Harrison, MD and MPH
Clinical Professor of Medicine, Division of Occupational and Environmental Medicine, University of California San Francisco

Jill Johnston, PhD, MS
Assistant Professor of Environmental Health, Department of Population and Public Health Sciences, Keck School of Medicine, University of Southern California

Kenneth Kloc, PhD and MPH
Staff Toxicologist, Office of Environmental Health Hazard Assessment, California EPA

Lisa McKenzie, PhD and MPH
Clinical Assistant Professor, Department of Environmental and Occupational Health, Colorado School of Public Health, University of Colorado Denver Anschutz Medical Campus

Thomas McKone, PhD
Professor Emeritus, School of Public Health, University of California, Berkeley
Affiliate, Energy Technologies Area, Lawrence Berkeley National Laboratory

Mark Miller, MD, MPH
Director, Children's Environmental Health Center, Office of Environmental Health Hazard Assessment, California EPA
Associate Clinical Professor, Division of Occupational and Environmental Medicine, University of California, San Francisco

Andrea Polidori, PhD
Advanced Monitoring Technologies Manager, South Coast Air Quality Management District

CalGEM Questions for the California Oil and Gas Public Health Rulemaking Scientific Advisory Panel

CalGEM requests the California Oil and Gas Public Health Rulemaking Scientific Advisory Panel assistance with the following questions:

1. ***How would the panel characterize the level of certainty that proximity to oil and gas extraction wells and associated facilities in California causes negative health outcomes? Is there a demonstrated causal link between living near oil and gas wells and associated facilities and health outcomes?***

We have focused our review on epidemiological studies carried out in multiple oil and gas regions, including Colorado, which has a similar regulatory context as California. Given that similar environmental health hazards and risks are intrinsic to both conventional and unconventional oil and gas development (OGD), including exposure pathways, chemicals associated with hydrocarbon reservoirs, use of ancillary equipment, and non-chemical stressors (See section on "Similarities and Differences Between Unconventional and Conventional OGD"), the California Oil and Gas Public Health Rulemaking Scientific Advisory Panel (Panel) concludes that the full body of epidemiologic literature is relevant to assess the human health hazards, risks and impacts of upstream OGD in California.

Our Panel concludes with a high level of certainty[1] that the epidemiologic evidence indicates that close residential proximity to OGD is associated with adverse perinatal and respiratory outcomes, for which the body of human health studies is most extensive in California and other locations.

Studies on Oil and Gas Development and Perinatal Outcomes

Perinatal outcome studies provide the largest [19 studies][2] and strongest body of evidence linking OGD exposure during the sensitive prenatal period with adverse health effects. The majority of studies that examine perinatal effects found increased risk of adverse birth outcomes in those most exposed to OGD (measured using metrics including, but not limited to proximity, well density, and production volume). It should also be noted that adverse perinatal outcomes, including preterm births, low birth weight, and small-for-gestational age births

[1] In this document, the statement, "a high-level of certainty" is based on the professional judgement of all California Oil and Gas Public Health Rulemaking Scientific Advisory Panel (Panel) members in their assessment of the scientific evidence. In terms of panel process, all Panel members agree with the responses to the questions in this document. Any Panel member could have written a dissenting opinion, but no one requested to do so. This document reflects the perspective of the Panel members and not necessarily the opinions of their employers or institutions.

[2] Apergis et al., 2019; Busby & Mangano, 2017; Caron-Beaudoin et al., 2020; Casey et al., 2016; Currie et al., 2017; Cushing et al., 2020; Gonzalez et al., 2020; Hill, 2018; Janitz et al., 2019; Ma, 2016; McKenzie et al., 2014, 2019; Stacy et al., 2015; Tang et al., 2021; Tran et al., 2020, *Forthcoming*; Walker Whitworth et al., 2018; Whitworth et al., 2017; Willis et al., 2021.

increase the risk of mortality and long-term developmental problems in newborns (Liu et al., 2012; Vogel et al., 2018) as well as longer term morbidity through adulthood (Baer et al., 2016; Barker, 1995; Carmody & Charlton, 2013; Frey & Klebanoff, 2016).

Perinatal Outcomes Associated with Conventional and Unconventional Oil and Gas Development

While many perinatal outcome studies outside of California focus on unconventional OGD (e.g., high-volume hydraulic fracturing), a recent review of the literature (Deziel et al., 2020), highlighted the need for an updated assessment of the health effects associated with OGD more generally, as both conventional and unconventional OGD operations present health risks, especially to those living in close proximity. This bolsters conclusions reached by the authors of the 2015 independent scientific study of hydraulic fracturing and well stimulation in California led by the California Council on Science and Technology (CCST) (Long et al., 2015) pursuant to Senate Bill 4 (2013, Pavley). Recent studies in California have reported associations between exposure to OGD and adverse birth outcomes, considering wells under production using enhanced oil recovery including cyclic steam injection, steam flooding and water flooding -- methods that do not meet the definition of unconventional development (Gonzalez et al., 2020; Tran et al., 2020, *Forthcoming*). Similar findings regarding adverse birth outcomes have been reported while examining unconventional OGD in Colorado, Oklahoma, Pennsylvania and Texas (Apergis et al., 2019; Casey et al., 2016; Cushing et al., 2020; Gonzalez et al., 2020; Hill, 2018; McKenzie et al., 2019; Stacy et al., 2015; Walker Whitworth et al., 2018; Whitworth et al., 2017). In the California independent scientific study on well stimulation pursuant to Senate Bill 4 (2013, Pavley), the authors concluded that while hydraulic fracturing introduces some specific human health risks, the majority of environmental risks and stressors are similar across conventional and unconventional oil and gas operations (Long et al., 2015; Shonkoff et al., 2015). Further, a handful of epidemiological studies explicitly examine potential differences in associations between conventional or unconventional oil or natural gas development and adverse outcomes. For example, Apergis et al. (2019) reported statistically significant reductions in infant health index within 1 km of both conventional and unconventional drilling sites in Oklahoma. <u>In summary, the Panel concludes with a high level of certainty that human health studies focused on unconventional and conventional OGD are relevant to consider in the California context where conventional development is most prevalent.</u>

Consistency Across Perinatal Epidemiology Studies

<u>We have a high level of certainty in the findings in the body of epidemiological studies for perinatal health outcomes because of the consistency of results across multiple studies that were conducted using different methodologies, in different locations, with diverse populations, and during different time periods</u> (see **Table 1** below). Most of these studies entail rigorous, high quality analyses (i.e., study designs that establish temporality based on large sample sizes, control for potential individual and area-level confounders, apply rigorous statistical

modelling techniques, and conduct sensitivity analyses to assess the robustness of effects). A variety of pollutants (e.g., $PM_{2.5}$ and air toxics) and other OGD stressors are associated with these same adverse birth outcomes (Dzhambov & Lercher, 2019; Nieuwenhuijsen et al., 2017; Shapiro et al., 2013), which further strengthens the evidence of the link between OGD and adverse perinatal outcomes. Therefore, the totality of the epidemiological evidence provides a high level of certainty that exposure to OGD (and associated exposures) cause a significant increased risk of poor birth outcomes.

Further, imprecision in exposure assessment or non-differential exposure misclassification in some of the epidemiological studies is more likely to attenuate observed relationships, thus leading to an underestimate of the true adverse impacts of OGD on birth outcomes (**Figure 1**). In environmental epidemiologic studies, researchers often use surrogates to estimate exposures or assign individuals to exposure categories; these surrogates have some measurement error associated with them. When these errors in assigning or classifying participant exposures are similar between exposed and unexposed or those with or without the health outcome, this is referred to as non-differential exposure misclassification. This type of "noise" in the data tends to dilute or attenuate the true exposure-response relationship, as illustrated by the hypothetical dashed line in **Figure 1**, which has a shallower slope compared to the hypothetical "true" solid line.

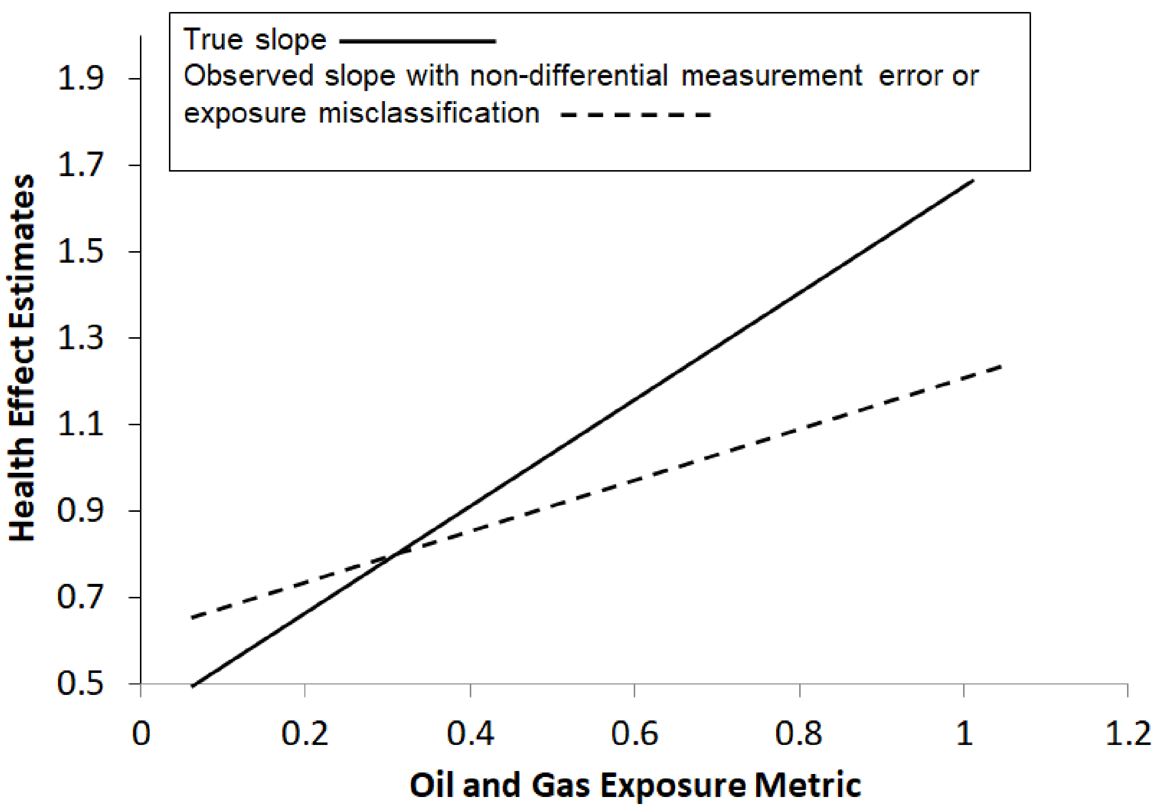

Figure 1. Effect of imprecise exposure estimates on a hypothetical exposure-response relationship (Source: Adapted from Seixas & Checkoway, 1995).

Respiratory Risks and Impacts from Oil and Gas Development

Respiratory health outcomes are the second most studied health outcomes in the epidemiological literature examining OGD, with eight peer-reviewed studies published to date. Two peer-reviewed studies in California found an association between OGD and self-reported and physician-diagnosed asthma, reduced lung function, and self-reported acute respiratory symptoms (e.g., recent wheeze) (Johnston et al., 2021; Shamasunder et al., 2018). Six studies in other oil and gas regions (Pennsylvania and Texas) reported an association between OGD and asthma exacerbations, asthma hospitalizations, and respiratory symptoms (Koehler et al., 2018; Peng et al., 2018; Rabinowitz et al., 2015; Rasmussen et al., 2016; Willis et al., 2018, 2020).

Epidemiological studies, by design, often use aggregate measures of exposure to account for multiple potential stressors and pathways associated with OGD (e.g., air pollution, noise pollution, groundwater and/or drinking water contamination). Many criteria air pollutants (e.g., particulate matter, ozone, nitrogen oxides) and hazardous air pollutants emitted from OGD have a well-established body of scientific literature indicating that exposure to these pollutants causes an increased risk of development and exacerbation of respiratory disease (Bolden et al., 2015; Ferrero et al., 2014). We reiterate the relevance of studies on both conventional and unconventional OGD for respiratory health outcomes. For example, (Willis et al., 2020) found that both conventional and unconventional natural gas development at the ZIP code level was associated with pediatric asthma hospitalizations in Texas.

Comparing The Body of Perinatal and Respiratory Outcome Studies Against The Bradford Hill Criteria for Causation

Below, we demonstrate how the body of epidemiological studies on the relationship between OGD and perinatal and respiratory outcomes meets the nine Bradford Hill Criteria for Causation (Hill, 1965; Lucas & McMichael, 2005). The Bradford Hill Criteria are used to evaluate the strength of epidemiological evidence for determining a causal relationship between an exposure and observed effect. These criteria are widely used in the field of epidemiology and public health practice to guide decision-making. After considering these criteria, the Panel concludes with a high level of certainty that there is a causal relationship between close geographic proximity to OGD and adverse perinatal and respiratory outcomes (**Table 1**).

Table 1. Application of the Bradford Hill Criteria for Causation to the peer-reviewed epidemiological literature on oil and gas development and perinatal and respiratory health outcomes.

Criteria for Causation (Bradford-Hill)	Description of Criteria	Perinatal Health Studies	Respiratory Health Studies
Strength of Association	Environmental studies commonly report modest effects sizes (i.e., relative to active tobacco smoking or alcohol consumption). A small magnitude of association can support a causal relationship, a larger association may be more convincing.	Reported effect sizes are in ranges similar to other well-established environmental reproductive and developmental hazards, such as $PM_{2.5}$ (Dadvand et al., 2013; C. Li et al., 2020). Some studies, particularly those in California, have found stronger effect estimates for OGD exposures among socially marginalized groups (Cushing et al., 2020; Gonzalez et al., 2020; Tran et al., 2020, *Forthcoming*).	Reported effect sizes are in ranges similar to other well-established environmental respiratory hazards. For example, effect sizes in reductions in lung function by Johnston et al. (2021) are similar in magnitude to reductions in lung function associated with secondhand smoke exposure among women (Eisner, 2002) and reductions in lung function among adults living near busy roadways (e.g., (Kan et al., 2007).
Consistency	Consistent findings observed by different persons in different places with different samples strengthens the likelihood of an effect.	Adverse birth outcomes have been observed in multiple studies using multiple methods in different populations at different times and locations (e.g., California, Pennsylvania, Colorado, Texas). While there is some variation in findings by specific perinatal outcomes, the overall body of evidence is highly consistent in supporting the association between OGD and adverse perinatal outcomes.	Various respiratory health outcomes are evaluated in the literature. For asthma -- the most commonly studied respiratory health outcome -- studies across California, Pennsylvania and Texas consistently show an association between OGD and asthma-related metrics (asthma prevalence, exacerbations, pediatric hospitalizations) (Koehler et al., 2018; Rasmussen et al., 2016; Shamasunder et al., 2018; Willis et al., 2018, 2020) .

Criteria for Causation (Bradford-Hill)	Description of Criteria	Perinatal Health Studies	Respiratory Health Studies
Specificity	Causation is likely if there is no other likely explanation.	All peer-reviewed birth outcome studies included in our review controlled for other potential confounders by (i) accounting or adjusting for other individual-level or area-level factors (e.g., other air pollution sources, neighborhood socioeconomic status) in the analysis (Casey et al., 2016; McKenzie et al., 2014; Tran et al., 2020, *Forthcoming*). Other studies applied statistical modeling approaches such as difference-in-difference that accounts for temporal and spatial trends that may confound observed effects (Willis et al., 2021).	Most respiratory health studies have controlled for other potential explanatory or confounding factors by (i) accounting or adjusting for other individual-level (e.g., smoking status) or area-level factors (e.g., other air pollution sources) in the analysis (Johnston et al., 2021; Koehler et al., 2018; Peng et al., 2018; Rabinowitz et al., 2015; Rasmussen et al., 2016; Willis et al., 2018, 2020), or in the study design, such as utilizing a difference-in-difference methodology (Peng et al., 2018; Willis et al., 2018).
Temporality	Exposure precedes the disease.	Most birth outcomes studies have proper temporal alignment between exposure and outcome and use a retrospective cohort, case control or other study design that allows retroactive assessment of exposures to OGD occurring before the onset of disease. They do not consider exposure that occurred at the time of disease or oil and gas wells drilled after the disease.	Some respiratory health studies do not allow for assessments of exposure that predate disease. However, of the studies with the proper temporal alignment (Johnston et al., 2021; Koehler et al., 2018; Peng et al., 2018; Rasmussen et al., 2016; Willis et al., 2018), authors report statistically significant associations between OGD and oral corticosteroid medication orders, asthma hospitalizations and asthma-related emergency department visits.

Criteria for Causation (Bradford-Hill)	Description of Criteria	Perinatal Health Studies	Respiratory Health Studies
Biological Gradient (Dose-Response)	Greater exposure leads to a greater likelihood of the outcome.	Some studies have found dose-response relationships based on oil and gas production volume categories or metrics of inverse distance weighting and/or oil and gas well density in California and elsewhere (Casey et al., 2016; McKenzie et al., 2014, 2019; Tang et al., 2021; Tran et al., 2020).	Larger reductions in lung function observed with decreased distance from active oil development sites (Johnston et al., 2021).
Plausibility	The exposure pathway and biological mechanism is plausible based on other knowledge.	Individual health-damaging chemical pollutants are well-understood to be emitted from OGD (e.g., $PM_{2.5}$, benzene) and established as contributing to increased risk for the same adverse perinatal outcomes observed in the epidemiology studies. Stressors associated with OGD (e.g., psychosocial stress; (Casey et al., 2019) can also contribute to increased adverse perinatal outcomes.	Many air pollutants associated with OGD are well-known to contribute to respiratory morbidity and mortality, including exacerbations of existing respiratory conditions (Guarnieri & Balmes, 2014).
Coherence	Causal inference is possible only if the literature or substantive knowledge supports this conclusion.	In particular, the body of peer-reviewed literature is converging towards singular directions for adverse perinatal outcomes.	The body of peer-reviewed literature points in a singular direction for adverse respiratory health outcomes.

Criteria for Causation (Bradford-Hill)	Description of Criteria	Perinatal Health Studies	Respiratory Health Studies
Experiment	Causation is a valid conclusion if researchers have seen observed associations in prior experimental studies.	N/A- Human population-based experimental studies are not available due to ethical issues.	N/A- Human population-based experimental studies are not available due to ethical issues.
Analogy	For similar programs operating, similar results can be expected to bolster the causal inference concluded.	Pollutants well known to be emitted during OGD including benzene, toluene and 1,3 butadiene are listed as reproductive or developmental toxicants under Prop 65 and thus are recognized as such by the State of California (CalEPA OEHHA, 2021). EPA's current Integrated Science Assessments of particulate matter and tropospheric ozone conclude that the evidence is suggestive of, but is not sufficient to infer, a causative relationship between birth outcomes, including preterm birth and low birth weight, and $PM_{2.5}$ and long term ozone exposures (US EPA, 2019, 2020). Additionally, increased stress during pregnancy can alter fetal growth and length of gestation (Fink et al., 2012).	EPA's current Integrated Science Assessments of particulate matter and tropospheric ozone conclude that there is: a casual relationship between respiratory outcomes, including asthma and short term ozone exposure; and likely a causal relationship between respiratory outcomes, including asthma and: short and long term $PM_{2.5}$ exposure; and long term ozone exposure (US EPA, 2019, 2020).

Similarities and Differences Between Unconventional and Conventional Oil and Gas Development

Though definitions of conventional and unconventional OGD may differ across different regulatory and policy landscapes, the majority of OGD in California is often considered conventional, involving vertical drilling at shallower depths into target geologies that hold migrated hydrocarbons. These attributes of development are often considered in contrast to unconventional OGD, which can involve horizontal directional drilling in deeper wells to access source rock formations by increasing the permeability of these tight formations using mostly hydraulic fracturing. In addition, these unconventional operations are often accompanied with greater masses of material inputs (e.g., water, chemical additives, proppants) and a greater magnitude of liquid and solid waste outputs (e.g., flowback fluids and produced water). It should be noted, however, that hydraulic fracturing that takes place in California often uses fluids (gels) with higher concentrations of well stimulation chemicals than those fluids used in high-volume slick water hydraulic fracturing of source rock in other parts of the United States (Long et al., 2015).

However, many environmental and health hazards and risks are intrinsic to both conventional and unconventional OGD (Hill et al., 2019; Jackson et al., 2014; Lauer et al., 2018; Stringfellow et al., 2017; Zammerilli et al., 2014). $PM_{2.5}$ and nitrogen oxides emissions result from the use of diesel-powered equipment and trucks and hazardous air pollutants such as benzene, toluene, ethylbenzene and xylene (BTEX) occur naturally in oil and gas formations, regardless of the type of extraction method employed. Noise pollution, odors, and landscape disruption are inherent to OGD. Investigations in other oil and gas states have noted radioactivity on particles downwind from unconventional oil and gas wells (Li et al., 2020b) and in sediment downstream of water treatment plants that treat waste from conventional as well as unconventional oil and gas operations (Burgos et al., 2017; Lauer et al., 2018).

In California, policy, regulatory and scientific emphasis has been placed on well stimulation activities, including hydraulic fracturing, matrix acidizing and acid fracturing. The 2015 Independent Scientific Assessment on Well Stimulation in California, which focused primarily on well stimulation activities pursuant to Senate Bill 4 (2013, Pavley), reported the following key conclusion: *“The majority of impacts associated with hydraulic fracturing are caused by the indirect impacts of oil and gas production enabled by the hydraulic fracturing”* (Long et al., 2015). Indirect impacts relevant to human health for the purposes of the study included: “proximity to any oil production, including stimulation- enabled production, could result in hazardous emissions to air and water, and noise and light pollution that could affect public health” (Long et al., 2015). Additionally, a recent evaluation of chemical usage during OGD in California found significant overlap in chemical additives used for well stimulation (including hydraulic fracturing) and those used in routine activities, such as well maintenance (Stringfellow et al., 2017).

2. What are the air pollutants released from these activities that cause negative health outcomes? How do we know exposure to these is likely from oil and gas extraction wells and associated facilities, as opposed to other sources?

The wells, valves, tanks and other equipment used to produce, store, process and transport petroleum products at both unconventional and conventional OGD sites are associated with emissions of toxic air contaminants, hazardous air pollutants and other health-damaging non-methane VOCs (Helmig, 2020; Moore et al., 2014). Diesel engines used to power on-site equipment and trucks at unconventional and conventional OGD sites directly emit health-damaging hazardous air pollutants, fine particulate matter ($PM_{2.5}$), nitrogen oxides and volatile organic compounds (VOCs) (CalEPA OEHHA, 2001). Many VOCs and nitrogen oxides are precursors to ground level ozone (O_3) formation, another known health harming pollutant. Hazardous air pollutants that are known to be emitted from OGD sites include benzene, toluene, ethylbenzene, xylenes, hexane and formaldehyde--many of which are known, probable or possible carcinogens and/or teratogens and which have other adverse effects for non-cancer health outcomes (CalEPA OEHHA, 2008, 2009; Moore et al., 2014). In the San Joaquin Valley Air Pollution Control District, OGD activities are responsible for the majority of emissions of multiple toxic air contaminants including acetaldehyde, benzene, formaldehyde, hexane and hydrogen sulfide (**Figure 2**) (Brandt et al., 2015; Long et al., 2015).

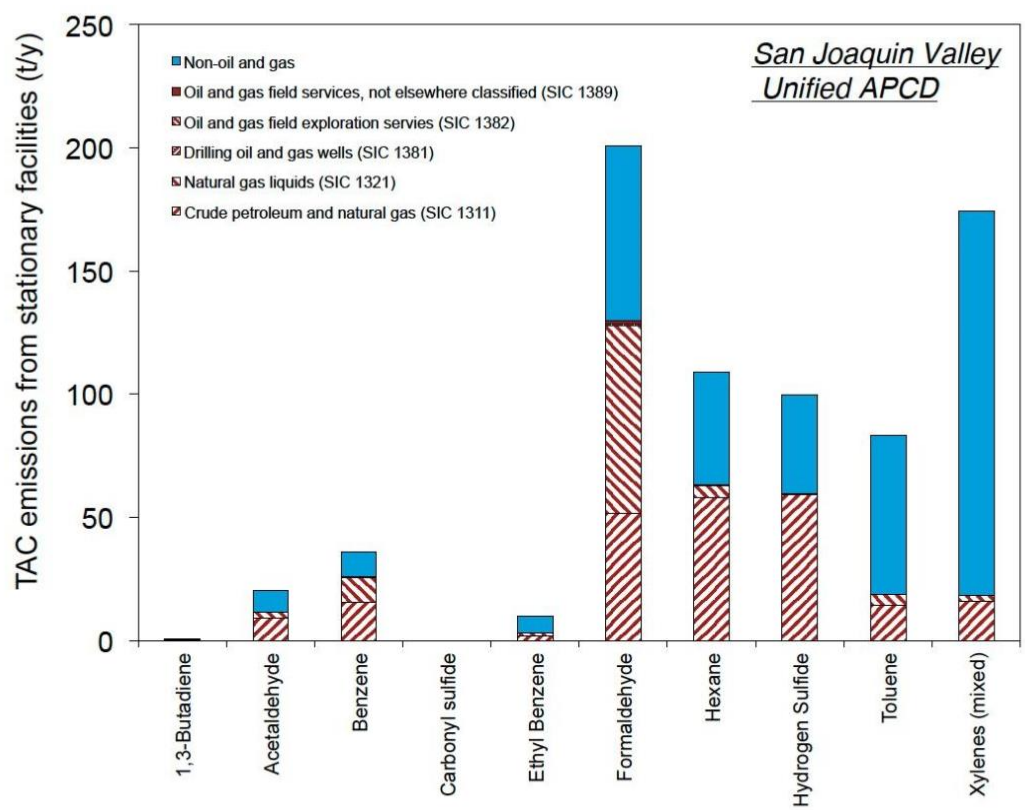

Figure 2. **Toxic Air Contaminant emissions from stationary facilities in the San Joaquin Valley Air Pollution Control District (Source: (Brandt et al., 2015).**

A recently published study using statewide air quality monitoring data from California investigated whether drilling new wells or increasing production volume at active wells resulted in emissions of $PM_{2.5}$, nitrogen dioxide (NO_2), VOCs, or O_3 (Gonzalez et al., 2021)**.** To assess the effect of oil and gas activities on concentrations of air pollutants, the authors used daily variation in wind direction as an instrumental variable and used fixed effects regression to control temporal factors and time-invariant geographic factors. The authors documented higher concentrations of $PM_{2.5}$, NO_2, VOCs, and O_3 at air quality monitoring sites within 4 km of pre-production OGD well sites (i.e., wells that were between spudding and completion) and 2 km of production OGD well sites, after adjusting for geographic, meteorological, seasonal, and time trending factors. In placebo tests, the authors assessed exposure to well sites downwind of the air monitors and observed no effect on air pollutant concentrations. **Table 2** summarizes the increases in each pollutant for each additional upwind well site by distance.

Table 2. Summary of air pollutant concentrations measured between 2006-2019 at 314 air quality monitoring sites in the EPA Air Quality System for California (Gonzalez et al., 2021*).*

Distance	$PM_{2.5}$ µg/m^3*	NO_2 ppb	VOCs (ppb C)*	O_3 (ppb)
Estimated increase for each additional upwind pre-production well site				
Within 2 km	2.35 (0.81, 3.89)	2.91 (0.99, 4.84)	No increase	no increase
2-3 km	0.97 (0.52, 1.41)	0.65 (0.31, 0.99)	No increase	0.31 (0.2, 42)
3-4 km	no increase	no increase	no increase	0.14 (0.05, 0.23)
Estimated Increase for each 100 BOE of total oil and gas upwind production volume				
1 km	1.93 (1.08, 2.78)	0.62 (0.37, 0.86)	0.04 (0.01, 07)	no increase
1-2 km	no increase	no increase	no increase	0.11 (0.08, 0.14)

*No $PM_{2.5}$ or VOC monitoring sites with 1 km of pre-production well sites; BOE, barrels of oil equivalents.

These multiple stressors, along with other physical factors such as noise and vibration, are consistently found in exposure studies to be measurably higher near oil and gas extraction wells and other ancillary infrastructure in California. As such, the Panel concludes with a high level of certainty that concentrations of health-damaging air pollutants, including criteria air pollutants and toxic air contaminants, are more concentrated near OGD activities compared to further away.

3. ***Does the evidence evaluated clearly support a specific setback? If so, what is this setback distance and what oil and gas extraction activities would it specifically apply to? What is the supporting evidence?***
    a. ***How does this evidence justify the recommended setback distance, as opposed to another distance?***

Existing epidemiologic studies were not designed to test and establish a specific "safe" buffer distance between OGD sites and sensitive receptors, such as homes and schools. Nevertheless, studies consistently demonstrate evidence of harm at distances less than 1 km, and some studies also show evidence of harm linked to OGD activity at distances greater than 1 km. In addition, exposure pathway studies have demonstrated through measurements and modelling techniques, the potential for human exposure to numerous environmental stressors (e.g., air pollutants, water contaminants, noise) at distances less than 1 km (e.g., Allshouse et al., 2019; Holder et al., 2019; McKenzie et al., 2018; DiGiulio et al., 2021; Soriano et al., 2020), and that the likelihood and magnitude of exposure decreases with increasing distance.

b. ***What are the health benefits from this setback? Can the panel quantify them or recommend a methodology CalGEM can use to quantify them? Can the panel establish that these health benefits can only be achieved with the setback? Or can they also be achieved with mitigation controls?***

Figure 3 presents a hierarchy of strategies to reduce human health hazards, risks and impacts from OGD activities. **Table 3** presents the advantages and disadvantages of each strategy from an environmental public health perspective.

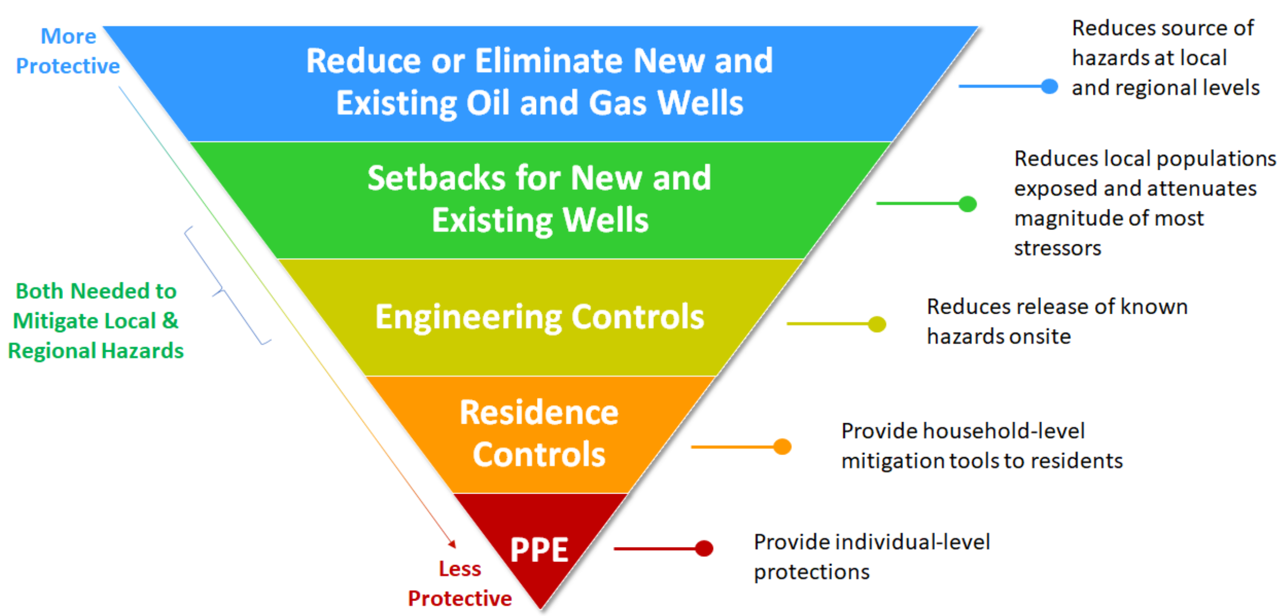

Figure 3. Hierarchy of strategies to reduce or eliminate public health harms for OGD activities. Note: the use of the term "wells" includes the ancillary infrastructure used to develop, gather and process oil and gas in the upstream oil and gas sector.

At the top of Figure 3 is the most health protective strategy: to stop drilling and developing new wells, phase out existing OGD activities and associated infrastructure, and properly plug remediate legacy wells and ancillary infrastructure.

If the development of oil and gas is to continue, the greatest health benefits would be gained from a strategy that includes the next two controls in the hierarchy depicted in Figure 3: the elimination of new and existing wells and ancillary infrastructure within scientifically informed setback distances and the deployment of engineering emission controls and associated monitoring approaches that lead to rapid leak detection and repair for new and existing wells and ancillary infrastructure. Because air pollutant concentrations and noise levels decrease with increasing distance from a source, adequate setbacks can reduce harm to local populations by reducing exposures to air pollutants and noise directly emitted from the OGD activities. However, setbacks do not reduce harms from OGD contributions to regional air pollutant levels, such as secondary particulate matter and ozone, or greenhouse gases, such as methane, which are nearly always co-mingled with health-damaging air pollutants (Michanowicz et al., *Forthcoming*). Engineering controls that reduce emissions at the well site are also necessary to reduce these harms.

Engineering controls include cradle-to-grave noise and air pollution emission mitigation controls on OGD infrastructure including new, modified and existing infrastructure, and proper abandonment of legacy infrastructure, prioritizing those nearest to residential sites and schools and those associated with the highest emissions, leaks and other environmental hazards.

However, engineering controls can fail and engineering solutions may not be available for or economically feasible to handle all of the complex stressors generated by OGD, including multiple sources and types of air pollution, noise pollution, light pollution, water pollution, and other stressors. Therefore, neither setbacks or engineering controls alone are sufficient to reduce the health hazards and risks from OGD activities -- both approaches are needed in tandem.

Finally, we note that while outside of CalGEM's jurisdiction, setbacks for new construction of housing or schools at a certain distance from existing or permitted OGD sites (commonly referred to as reverse setbacks), should be considered.

Table 3. Advantages and Disadvantages of Oil and Gas Development Control Strategies from an Environmental Public Health Perspective.

Control Strategy	Description	Advantage	Disadvantage
Elimination	Eliminate or reduce new and existing wells and ancillary infrastructure in combination with proper plugging and abandonment of wells and other legacy infrastructure.	Eliminates the source of nearly all environmental stressors (e.g., air and water pollutants, noise); protects local and regional populations	None.
Setbacks	Increase the distance between OGD hazards and sensitive receptors.	Reduces risk of exposures to populations living near OGD sites; environmental stressors are generally attenuated with increasing distance.	Setbacks alone without coupled engineered mitigation controls allow continued release of hazards and therefore does not adequately address air pollutant and greenhouse gas emissions from OGD and their impacts on regional air quality and the climate.
Engineering Controls	Reduces or eliminates release of specific hazards on site.	Reduces or eliminates certain hazards and therefore can have local and regional environmental public health benefits.	Tends to be disproportionately focused on air pollutant emissions. Often not feasible to apply engineering solutions to multiple, complex stressors each requiring different control technologies (e.g. noise, air and water impacts, social stressors) and lacks the important factor of safety provided by a setback when engineering controls fail.
Residence Controls	Provides households with devices to reduce hazard at the home (e.g., water filter, light-blocking shades, air filters).	Reduces intensity of certain hazards to nearby communities at the household level.	Places burden on individuals and households to use devices properly and to maintain and regularly replace controls to maximize effectiveness. Not feasible to apply devices to address numerous, complex stressors.
Personal Protective Equipment	Provide individuals with devices to reduce exposure (e.g., respiratory masks, ear plugs, eye masks).	Reduces intensity of exposure of certain hazards to nearby individuals.	Places burden on individuals to use PPE consistently and properly and is not feasible for the complex stressors.

Attributable Risk Calculations

One method to estimate health harms from OGD is to use the measures of association from the epidemiologic literature and population counts to calculate the excess number of specific health outcomes. This is what is known as an attributable risk method. We may be able to derive these estimates in the final report for birth outcomes using estimates of population counts for women of reproductive age in California living near OGD sites. We will also attempt to derive similar estimates for respiratory outcomes by using age appropriate population counts near OGD sites. This attributable risk method can allow us to estimate the number of adverse perinatal or respiratory cases that are attributable to OGD exposures and could be attenuated through the implementation of elimination or setback strategies.

c. ***Can the panel quantify or recommend a methodology CalGEM can use to quantify the health benefits associated with mitigation controls?***

The Panel was not tasked to estimate health benefits of various setbacks and mitigation strategies, which pose significant methodological challenges and would require considerable time and effort. Among the challenges is the need to consider the benefits of reducing multiple stressors -- multiple air pollutants and other chemicals, noise, vibration, light, subsurface contamination, etc.

Known Health Benefits of Reducing Air and Noise Pollution

There is a significant body of literature and available tools that address the potential health benefits that can be achieved by reducing air and noise pollution exposures. The National Institute of Environmental Health Sciences has linked air pollution and specifically $PM_{2.5}$ to respiratory disease, cardiovascular disease, cancer, and reproduction harm and provides references supporting these links (NIEHS (National Institute of Environmental Health Sciences), 2021). Schraufnagel et al. (2019) examined in detail the health benefits of air pollution reductions in different geographic regions. Friedman et al. (2001) showed that improvements in air quality in preparation for the 1996 Atlanta Olympics resulted in significantly lower rates of childhood asthma events, including reduced emergency department visits and hospitalizations. Avol et al. (2001) demonstrated that children in southern California who moved to communities with higher air pollution levels had lower lung function growth rates than children who moved to areas with lower air pollution levels. Gauderman et al. (2015), examining the impact of reductions in $PM_{2.5}$ and nitrogen dioxide in the Los Angeles air basin, found that children who grew up after air quality improvements had less than ½ the chance of having clinically low lung function results. Ha et al. (2014) found $PM_{2.5}$ exposures in all trimesters to be significantly and positively associated with the risk of all adverse birth outcomes.

In an analysis of noise exposure reductions. Based on sound levels measured and/or modeled across the US together with an EPA exposure- response model for levels exceeding EPA standards, Swinburn et al. (2015) found that a 5-dB noise reduction scenario in communities with noise exceeding EPA standards would reduce the prevalence of hypertension by 1.4% and coronary heart disease by 1.8%. The types of health-benefit studies noted here provide a basis for conducting a health-benefits analysis using a tool such as US EPA's Environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP-CE) (US EPA, 2021).

Possible Approaches to Quantify Health Benefits

CalGEM could obtain estimates of the health benefits achieved from different mitigation strategies individually or in combination with tools such as the Community Multiscale Air Quality Model (CMAQ) (Binkowski & Roselle, 2003) and/or other exposure assessment tools and link model output to EPA's BenMAP-CE (US EPA, 2021). However, these models and approaches are only focused on air quality and noise. It should also be noted that a significant drawback of using BenMAP-CE for this application is that it only considers impacts from criteria air pollutants and not from toxic air contaminants or other emerging air pollutants.

BenMAP-CE estimates the number and economic value of health impacts resulting from changes in air pollution concentrations. BenMAP-CE estimates benefits in terms of the reductions in the risk of premature death, heart attacks, and other adverse health effects. BenMAP-CE requires as input, pollutant concentrations at a scale that matches with population data. These concentrations can be obtained from a model such as CMAQ (Binkowski & Roselle, 2003) or from a monitoring network. BenMAP-CE takes the concentration fields for a base case and then for a pollution reduction (or increase) to assess health benefits (or detriments). BenMAP-CE then estimates changes in health endpoints, allowing the user to specify the concentration–response function and either use built-in population and baseline mortality rates or specify them as inputs.

It should be noted that in order to use a model such as BenMAP-CE to assess health benefits of setbacks and mitigation controls at well sites across California would involve a significant level of time and effort in data collection and model executions. In addition, these models are limited to characterizing the health benefits of criteria air pollutant reductions, but do not account for other OGD related exposures such as toxic air contaminants, other chemical exposures and exposures to other stressors through other environmental pathways (e.g., water and noise). Additionally, and importantly, the lack of spatially resolved emissions data from upstream OGD introduces challenges when assessing local- and sub-regional scaled health impacts that would be required for calculating benefits of specific policies such as setbacks and emission control. As such, <u>attempts to quantify benefits using BenMAP-CE are likely to underestimate them</u>.

4. ***CalGEM is aware of health risk assessments, health impact assessments, air exposure studies, and workforce safety studies that have been conducted but were not evaluated as part of your preliminary advice. How do these studies align with your causation determination, any recommended setback distance, and recommendations on health benefits quantification?***

The Panel determined early in its deliberations that it would limit the studies assessed in its report to those in the peer-reviewed scientific literature. This criterion ensures that studies have been evaluated by scientists who have not been involved with the study but have expertise in the relevant topic area and/or the methods used to carry out analyses, prior to publication. The peer-review process helps to ensure that high quality data and scientific interpretations are at the core of the science-policy decision-making process. Authors of peer reviewed studies are more likely to have been questioned about their methods, data interpretations, and conclusions, leading to greater confidence in the results.

In addition, the Panel was not tasked with assessing occupational studies. If CalGEM staff are aware of any peer-reviewed studies that were not included in our preliminary advice, we encourage them to send the Panel references so that we can evaluate them for inclusion in the final report. We intend to scan the literature again to assess whether relevant studies have been published since we completed the draft report. Should additional peer-reviewed studies be identified, the Panel will evaluate them to determine if they align with the scope of the report and should be added.

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Exhibit 2 of 13 - Collier-Oxandale 2020. Using Gas-Phase Air Quality Sensors to Disentangle Potential Sources in a Los Angeles Neighborhood

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Using Gas-Phase Air Quality Sensors to Disentangle Potential Sources in a Los Angeles Neighborhood

Ashley Collier-Oxandale,[1] Nicole Wong,[2] Sandy Navarro,[3] Jill Johnston,[4] and Michael Hannigan[5]

Abstract

In the late summer of 2016, our team deployed a network of low-cost air quality sensing systems in partnership with community-based organizations in a neighborhood in South Los Angeles, California. Residents of this community were concerned about possible emissions from local oil and gas activity, however in addition to these potential emissions, the neighborhood is also subject to a complex mixture of pollutants from other nearby sources including major highways. For this deployment, metal-oxide VOC sensors were quantified to provide methane (CH_4) and total non-methane hydrocarbon (TNMHCs) concentration estimates. This data along with other sensor signals, meteorological data, and community member observations was used to examine the composition and possible origins of observed emissions. The sensor network displayed expected environmental trends and highlighted short-term elevations in CH_4 and/or TNMHCs, which we were then able to investigate more closely. The results indicated that sources of both combusted and volatilized hydrocarbons were likely affecting air quality throughout the community, including near the site of the local oil and gas activity. This deployment may serve as a model for how multi-sensor systems deployed in networks can be leveraged to better understand sources in complex areas, potentially supporting future community-based air quality research.

Keywords: low-cost sensors, gas-phase sensors, air quality, multi-sensor, VOC sensors

1. INTRODUCTION

The implementation of the Clean Air Act has led to immense improvements in air quality, particularly at the regional scale. However, the benefits of air quality improvements have not been realized equally across communities and more attention could be focused on variability in air pollution at the local level (Miranda et al., 2011). Monitoring near roadways (~2 to 400 m) consistently observes steep pollutant gradients near high-traffic roads (Brugge et al., 2007) and residents living in close proximity may face elevated health risks. Concentrations of benzene and summed volatile organic compounds (VOCs) have been found to be twice as high outside of homes in areas with heavy traffic as compared to those with low traffic (Fischer et al., 2000). Sources other than roadways can drive this small-scale variability as well. In addition to traffic, residential ambient concentrations of VOCs have been measured at levels 1.5–4 times higher within 50 meters of an industrial source (e.g., petroleum hydrocarbons or BTEX compounds near gas stations or perchloroethylene near dry cleaners) (Kwon et al., 2006). Significantly higher concentrations of BTEX compounds and styrene have been measured on the fenceline of a refinery as compared to sites approximately a mile away (Mukerjee et al., 2016). Given the potential health risks posed by some of these compounds emitted by large and small-scale industries (Loh et. al., 2007), a more comprehensive understanding of the local air quality and the variability of pollutants within communities could inform actions to improve public health. More detail at the local level might be particularly valuable in high-density locations with many potential sources.

1.1. Motivation for Community-driven Air Monitoring in South Los Angeles

While Los Angeles, California (CA) has long been the subject of research and policies to address poor air quality resulting from numerous point and mobile emission sources, continued growth, topography, and meteorology (Kunzli et al., 2003), neighborhood level air quality measurements have been less well characterized. One potential source of air pollutants of concern to communities is urban oil and gas extraction. Los Angeles County is home to more than 5000 active and idle oil wells, with 850 of these located within the City of Los Angeles (Sadd & Shamasunder, 2015). Rapid development over the years has led to a “conflict in land usage” (Chilingar et al., 2005), which has resulted in the active wells and production sites in close proximity to high density residential areas and public services such as schools and hospitals (Shamasunder et al., 2018). Given the potential for the release of air toxics from these facilities, such as BTEX (benzene, toluene, ethylbenzene, and xylene) compounds (Adgate et al., 2014; Helmig et al., 2014; Moore et al., 2014), increased near-source monitoring could help to characterize the impact on local air quality. Motivated by

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a concern for their health, residents of these communities often seek ways to collect more information or data to better understand their exposure and potentially facilitate action to reduce exposure (Brown, 1992). The increasing availability of more accessible environmental monitoring technologies, coupled with greater engagement, could support local community-based air quality research projects.

1.2. Background on Low-Cost Air Quality Sensors

One of these increasingly accessible technologies is low-cost air quality sensors, which have the potential to provide preliminary data to inform more targeted studies, to supplement existing monitoring networks, and to aid in the quicker detection of pollution hotspots (Snyder et al., 2013). The cost of these systems typically ranges from approximately $500 -$5000 each making the deployment of networks of sensor systems more feasible. Furthermore, because of the lower costs and the relatively simple deployment and operation procedures, this technology is well-suited to support community-based investigations (Shamasunder et al., 2018). However, an ongoing challenge associated with the use of low-cost sensors is ensuring high quality data. These sensors exhibit cross-sensitivities to environmental parameters and confounding pollutants (Lewis et al., 2016). Significant research, both in the lab and the field, has been undertaken to better understand and mitigate these cross-sensitivities as well as to develop different approaches to calibration methods and models (De Vito et al., 2008; Eugster & Kling, 2012; Mead et al., 2013; Piedrahita et al., 2014; Leidinger et al., 2014; Masson et al., 2015a & 2015b; Sadighi et al., 2018; Hagan et al., 2018; Kizel et al., 2018; Collier-Oxandale et al., 2018a; Collier-Oxandale et al., 2019). Beyond sensor quantification, researchers have explored the use of sensors in various applications such as studying the spatial variability of pollutants (Bart et al., 2014; Moltchanov et al., 2014; Sadighi et al., 2018; Cheadle et al., 2017), examining indoor air quality (Casey et al., 2018), to better understand specific point sources (Thoma et al., 2016; Yuval et al., 2019), and to support personal exposure monitoring (Jerrett et al., 2017, English et al., 2016).

Using low-cost VOC sensors can be particularly challenging given their typical lack of selectivity and susceptibility to interferents (Spinelle et al., 2017). However, there are studies illustrating the use of VOC sensors to detect methane (CH_4) at ambient levels as well as studies where unique techniques (e.g., multi-sensor arrays or temperature-controlled operation) have been used to identify target VOCS in the presence of confounders (Eugster & Kling, 2012; Leidinger et al., 2014). Studies have also explored the use of the sensors in complex ambient environments (Collier-Oxandale et al., 2018a & 2019), and how machine learning may be used with data from sensor arrays to identify source types (Thorson et al., 2019). As quantification approaches for VOC sensors continue to improve and best practices are established it is possible that these sensors could play a valuable role, alongside other types of low-cost air quality sensors, in addressing environmental inequities by helping to identify communities or neighborhoods overburdened by air pollution.

1.3. This Study

In this paper, we apply previously demonstrated approaches to estimate methane (CH_4) and total non-methane hydrocarbon (TNMHC) concentrations using measurements from a low-cost sensor network (Collier-Oxandale et al., 2018a & 2019). These estimates are then utilized along with supplementary data to study air quality trends and identify potential emission events at the local level in a South Los Angeles neighborhood. This project was conducted in a participatory manner and in partnership with two local, community-based organizations, Redeemer Community Partnership and Esperanza Community Housing. The deployment spanned primarily two neighborhoods in South Los Angeles, West Adams and North University Park. In both communities, problems such as poverty and housing insecurity contribute to community vulnerabilities. West Adams is made up of 87% residents of color, including 58% Latino and 20% African American. Furthermore 68% of residents live at or below 200% the poverty line (Shamasunder et al., 2018). University Park is predominantly Latino at 76% and here 72% of residents are living at or below 200% the poverty line (Shamasunder et al., 2018). Prior studies have demonstrated the reality of environmental injustices resulting in higher levels of exposure to air pollutants in minority and socioeconomically disadvantaged communities (Souza et al., 2009; Marshall, 2008; Clark et al., 2017). In some cases, odors or the visibility of industrial activities (e.g. acidization or flaring) may also contribute to increased stress or adverse effects on residents' quality of life (Beloff et al., 2000). Driven by community concerns, the two partner organizations brought awareness to potential adverse impacts of neighborhood oil drilling on residentials health and environmental quality (Sadd & Shamasunder, 2015). Informed by community concerns, we piloted an approach using low-cost sensors in a complex urban environment with the goal of learning more about local sources. Furthermore, the use of a multi-sensor platform along with the various analysis techniques shared in this paper may serve as a model for future community-based air quality research projects.

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2. METHODS

2.1. Deployment Overview

Fifteen low-cost sensing systems were deployed for a period of 8 weeks, from late summer through early fall 2016, in a community in South Los Angeles. Figure 1 depicts the sampling sites in relation to sources of interest; the sites are distributed on either side of and at varying distances away from the major highways indicated by black lines and an active multi-well oil extraction site indicated by a red star. The community identified the extraction site as being of interest, as a result much of the analysis examines spatial and temporal trends with respect to this location. The sampling sites were based on community interest, recommendations by researchers, and feasibility of access. Fourteen of the sites were located within a roughly 5×5 km area. Sites C1 and C2 were selected as they allowed for continuous co-location with reference instruments providing additional validation data. The neighborhood in which the sensor systems were deployed is primarily high density residential with some commercial and industrial land use. While only the major highways are indicated, some sites were located on high-traffic roads where substantial vehicle emissions can occur as well. While there are other active and inactive oil extraction and processing sites in the area, there were no active drill sites immediately near any sampling site other than the one already noted. Other potential local sources of VOCs would include, most prominently, gas stations, autobody shops, and dry cleaners. While the oil extraction facility is the closest potential source to sites E1 and E2, there is also a dry cleaner to the south of site E1 and an auto repair shop to the southwest of E1. There are several gas stations to the north, near site N5, and to the east, near site R4 and close to the highway. . Several other potential point sources, such as dry cleaners and auto body shops, are located throughout the community and on all sides of the two surrounding highways.

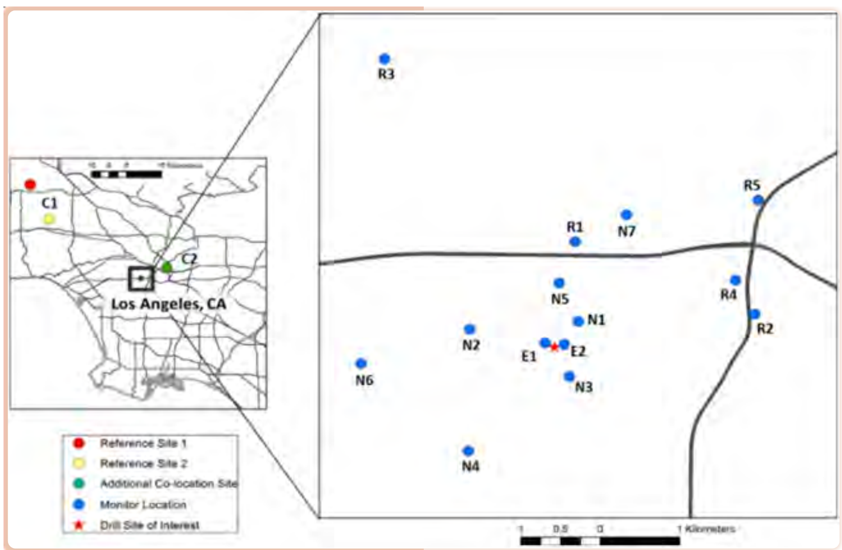

Figure 1:

Map of sampling sites and major sources of interest. Note that the Y-Pod locations have been approximated to the center of their respective blocks in order to protect participant identities. The first initial is indicative of the site type: N – neighborhood site, R – near roadway site, E – near oil extraction site, C – ongoing co-location site (note, Reference Site 1 was not used throughout the field deployment and thus does not have an additional label associated with a Y-Pod).

Placement of the systems at each site was primarily based on safety, convenience, and resident preference, although factors such as elevation above the ground and optimal access to air flow representative of surrounding conditions were also considered. As observed in a previous study, intra-site variability can occur and may be driven by sources in close proximity to the site that the sensors may or may not be well-positioned to detect (Collier-Oxandale et al., 2018b). For this reason, we ensured that the two Y-Pods adjacent to the site of interest had a "line-of-sight" to the potential source.

As previously described, the project utilized community-based participatory research methods. Together we worked with local partners to plan the project, choose the sampling sites, and conduct the sampling with assistance from local residents and businesses who hosted the monitors. Partners also assisted with finding and hiring a local field technician to check the sensor systems periodically and collect the data. As part of the project a Memorandum of Understanding (MOU) was developed and signed by all partners to ensure a mutual understanding of the limitations of sensor technology and study objectives as well as to ensure ongoing communication occurred, particularly around the dissemination of the results of the project. Further, we integrated local knowledge and observations of community members. Following the deployment, we were provided with a log of observed activity at the drill site and records of noise and odor complaints.

2.2. Low-Cost Sensing Systems

This study used an open-source, low-cost sensor system. These systems, termed U-Pods or Y-Pods, include various commercially

Feedback

available sensors, including metal oxide semi-conductor (MOx), electrochemical (EC), and non-dispersive infrared (NDIR) sensors for measuring gas-phase pollutants and other environmental parameters (see Table S1 and Figure S1). U-Pods and Y-Pods are iterations of the same design with some minor differences in the hardware and software intended to increase the reliability of the platform in the updated version; more details are available in previous publications (Masson et al., 2015b; Sadighi et al., 2018; Collier-Oxandale et al., 2018a & 2018b; Casey et al., 2018; Cheadle et al., 2017; Casey & Hannigan., 2018, Collier-Oxandale et al., 2019).

The sensors that this analysis relies on primarily are the Figaro TGS 2600 and the Figaro TGS 2602, both of which are MOx sensors. These sensors are described by the manufacturer as intended for the detection of "air contaminants", typically used in industrial applications. The datasheets list different compounds each sensor is responsive to, which along with previous research, suggests that the two models exhibit unique selectivities (Figaro, 2015a & 2015b, Collier-Oxandale et al., 2019). The stated detection ranges for both is 1 – 30 ppm (Figaro, 2015a & 2015b), however, this does not take into account the approach of utilizing more advanced signal processing techniques. For example, researchers have explored the potential for the Figaro 2600 to detect CH_4 and the potential for the Figaro 2602 to detect individual, groups of, and total VOCs (Becher et al., 2010; De Vito et al., 2011; Eugster & Kling 2014; Collier-Oxandale et al., 2018a, 2018b, & 2019). An additional study focusing on the variability among multiple Figaro 2602 sensor responses observed relatively low intra-sensor variability over a period of a few hours when sensors were exposed to zero air (< 10 pbb VOCs) (Smith et al., 2017). During a longer period of 20 days high intra-sensor correlation was continually observed, however drift was also observed resulting in an increasing spread among the sensor signals over time (Smith et al., 2017). The authors suggested that deploying clusters of these sensors may mitigate this issue (Smith et al., 2017).

Another important issue is the susceptibility of low-cost air quality sensors to interferents. The performance of MOx sensors may be impacted by environmental conditions in a variety of different ways. For example, temperature can directly impact a sensor's hardware affecting its ability to function, temperature can also govern reaction rates between the metal oxide surface and the target gas in the atmosphere (Wang et al., 2010; Sun et al., 2012). MOx sensors' cross-sensitivity to other gases is especially problematic for low-cost VOC sensors, which tend to be sensitive to both a wide array of VOCs and confounding compounds (Spinelle et al., 2017). As an example, the Figaro TGS 2600 has been observed to be cross-sensitive to carbon monoxide (Collier-Oxandale et al., 2018a); while the Figaro 2602 is sensitive to compounds such as ammonia and hydrogen sulfide, in addition to an array of VOCS (Figaro, 2015b). It is possible that unknown interferents may be impacting the sensors as well.

2.3. Sensor Signal Processing & Quantification

2.3.1. Field Calibration

Given the susceptibility of low-cost sensors to temperature and humidity as well as confounding gases, calibration is a necessary step. While laboratory tests are useful for determining the capabilities of sensors, researchers have continually found that field co-locations allow for the generation of more accurate calibration models (Piedrahita et al., 2014; Castell et al., 2017). The reason for this is likely the large and dynamic range of environmental variables and presence of background pollutants, which cannot be adequately replicated in the lab. This technique involves co-locating sensors with reliable reference instrumentation before and after a field deployment and then using this data along with a technique such as multiple linear regression or machine learning to generate and evaluate a calibration model (Casey at al., 2019; Cross et al., 2017; Zimmerman et al., 2018). Using this method, the field co-location provides data to train the calibration model to detect the target pollutant amid environmental and background conditions that are ideally similar to those experienced during a field deployment.

While field co-locations tend to produce more robust calibration models, there are limitations to this approach. As the calibration model is based on the conditions experienced during the co-location period, if temperature or humidity exceeds the range experienced during co-location, then the model will be extrapolating and may produce less reliable pollutant estimates (Eapoaito et al., 2017). In one study exploring the transferability of calibrations between different locations, researchers observed that calibration models maintain higher performance when they are transferred between areas impacted by similar sources as compared to sites closer together geographically, but impacted by different pollutant sources (Casey & Hannigan, 2018). It has also been observed that high performance models utilizing techniques such as machine learning tend to over-fit to the conditions of the co-location site, which results in diminished performance at new locations (Vikram et al., 2019).

Feedback

In this study, the selection of co-location sites was based on availability and the support of local regulatory agencies, which allowed for both pre-deployment and post-deployment co-locations with high quality reference instruments (Table 1). The pre-deployment co-location, for CH_4 and TNMHCs occurred at a site in Los Angeles, this site was in a suburban area that, in general, tended to experience lower levels of the target pollutants. The post-deployment co-location for CH_4 occurred at a mixed-use site in Los Angeles similar to the field deployment sites in terms of land-use. The post-deployment co-location for TNMHCs occurred at a rural site north of Los Angeles in Shafter, CA. This site had some similarities to the field deployment sites in terms of potential nearby sources. While there are important differences to note between the co-location and field deployment sites, the calibration models utilize relatively simple multiple linear regression techniques as opposed to more complex machine learning techniques, which may support enhanced transferability of the models (Vikram et al., 2019).

Table 1:

Details of co-locations with reference instruments

Dates	Reference Instrument	Pollutants	Location
Pre: 8/1 – 8/4/2016	[a]Baseline Mocon Series 900 Analyzer	CH_4, TNMHCs	Los Angeles, CA
Post: 10/20 –10/28/2016	[a]Picarro cavity ring-down spectrometer	CH_4	Los Angeles, CA
Post: 11/2 – 11/12/2016	[b]Synspec Alpha 115	TNMHCs	Shafter, CA

[a]operated by SCAQMD,
[b]operated by SJVAD

2.3.2. Signal Processing and Calibration Models Initial sensor signal processing involves converting the data to a normalized resistance, removing data from the warm-up period, and calculating minute-medians from the raw data. This process is described in greater detail in previous publications (Collier-Oxandale et al., 2018a & 2019). This processed sensor data is then used along with the reference data to generate the calibration models (Table 2). The calibration models rely on data from the Figaro TGS 2600 and Figaro TGS 2602, made by Figaro Inc., along with environmental data (i.e., temperature and humidity) to convert sensor signals to concentrations. In total three models are used, two to estimate CH_4 levels and one to estimate TNMCH levels. The difference between the two CH_4 models is that the first model relies on data from a single VOC sensor while the second model incorporates data from both MOx VOC sensors. The first model was determined to be the best-fitting model in a previous study as it seemed to correct for complex temperature and humidity effects (Collier-Oxandale et al., 2018a), however subsequent work suggests that multi-sensor models may help address cross-sensitivities to some confounding pollutants and provided better overall estimates of target species (Collier-Oxandale et al., 2019). Therefore, both models are included in this analysis. For this study, we used the same model for both the multi-sensor CH_4 and TNMHC models. As demonstrated during previous work, multi-sensor calibration models with the same structure and based on the same sensor data, but different reference data can be specialized to target specific pollutants or groups of pollutants (Collier-Oxandale et al., 2019).

Feedback

Table 2:

Calibration Models

Model Name	Equation
Single Sensor CH_4	$C = \frac{Fig2600 - p_1 - p_3(T) - p_4(H^{\ 1}) - p_5(T_i) - p_7(T * H^{\ 1}) - p_8(T_d)}{p_2 + p_6(T)}$
Multi Sensor CH_4	$C = p_1 + p_2(Fig2600) + p_3(Fig2602) + p_4(Fig2600 * Fig2602) + p_5(T) + p_6(H) + p_7(T_i)$
Multi Sensor TNMHC	$C = p_1 + p_2(Fig2600) + p_3(Fig2602) + p_4(Fig2600 * Fig2602) + p_5(T) + p_6(H) + p_7(T_i)$

Predictors (lower case p with subscripts) are Fig2600 – R_s/R_0 for the Figaro 2600 sensor, Fig2602 – R_s/R_0 for the Figaro 2602 sensor, C – pollutant concentration, T – temperature, H – absolute humidity, T_i – continuous time, T_d – time of day. The predictor p_1 indicates an empirical constant.

2.3.3. Supporting Data & Additional Processing

Signals from EC carbon monoxide (CO) sensors and NDIR carbon dioxide (CO_2) sensors were also utilized in this analysis to better understand the composition of potential emissions events. In several studies, EC sensors from the same manufacturer have been used to examine spatiotemporal trends and to compare different approaches to sensor calibration (Mead et al., 2013; Cross et al., 2017; Zimmerman et al., 2018; Jerrett et al., 2017). Additionally, studies utilizing the EC CO sensor and the NDIR CO_2 listed in Table S1, have observed uncertainties of 0.1 – 0.44 ppm for CO and ~10 ppm for CO_2 (Piedrahita et al., 2014; Casey et al., 2018; Collier-Oxandale et al., 2018b). For this study, these signals were also quantified using field calibration. While it is important to continue to test the capability of these sensors, the work presented here will focus on the VOC sensor quantification and analysis. Other supplemental data used includes local wind speed and direction data collected using a low-cost anemometer and wind vane located at one of the deployment sites (E2).

Feedback

In addition to the inclusion of this supplemental data, a signal processing technique developed for atmospheric data was used to identify and remove the baseline from the pollutant data in order to highlight the short-term increases (Ruckstuhl et al., 2012). Heimann and colleagues (2015), demonstrated the application of this technique to low-cost sensor data to separate regional trends (represented by the baseline) from local events (apparent in the baseline-removed data). Figure 2 illustrates the application of this technique to a roughly two weeks of CH_4 data from a single site. In this figure, the diurnal trends are no longer present in the baseline-removed data and the increases that do occur are shorter in duration and do not seem to occur at regular intervals. These increases may represent “events” potentially driven by local air quality conditions or by another phenomena eliciting a response from the sensors. Wavelet analysis is another approach to baseline removal that has been used to study the variability of pollutants on different time scales (Etzion & Broday, 2018).

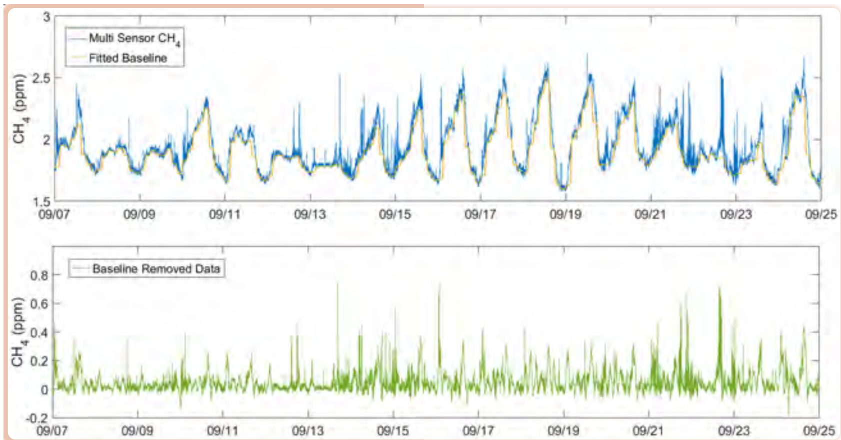

Figure 2:

Illustration of the baseline identification and removal approach

3. RESULTS & DISCUSSION

3.1. Sensor Performance Quantification

3.1.1. Targeting Methane and Non-methane Hydrocarbons Table 3 displays the average of the statistics that result from quantifying the 15 sensor systems to estimate CH_4 and TNMHCs. The complete statistics for each individual Y-Pod as well as timeseries of the reference data and fitted data are available in the Supplemental Materials (Tables S2 & S3, Figures S2 – S4). When compared to previous studies using the same sensors in the same platform, the results are similar suggesting there may be some consistency in the behavior of these MOx sensors. For instance, the average R^2 and RMSE for the testing data for a subset of three Y-Pods quantified in a previous study, using the single sensor calibration model for CH_4, (Collier-Oxandale et al., 2018a) were 0.74 and 0.18 ppm respectively. Comparing the performance of the two multi-sensor models in Table 3 to previous work reveals similarities as well. For CH_4, the multi-sensor model consistently exhibits improved performance over the single sensor model (Collier-Oxandale et al., 2018a & 2019). For TNMHCs, the R^2 resulting from using a multi sensor model to estimate a summed VOC signal was 0.59 (Collier-Oxandale et al., 2019).

Table 3:

Statistics from calibration model generation and validation, averages across 15 Y-Pods

	Training			*Testing*		
Target Pollutant	**R^2**	**RMSE**	**Mean Bias**	**R^2**	**RMSE**	**Mean Bias**
Single Sensor – CH_4 (ppm)	0.81	0.15	0.00	0.74	0.18	0.03
Multi-sensor – CH_4 (ppm)	0.88	0.11	0.00	0.80	0.16	0.07
Multi-sensor – TNMHC (ppb)	0.60	31.2	0.01	0.46	46.4	7.62

Feedback

In this analysis, the estimates resulting from both the single and multi-sensor CH_4 models are considered. While the multi-sensor model appears to improve estimates of CH_4 levels, as indicated by the performance statistics, it is possible that the inclusion of the second VOC sensor in the calibration model may increase the potential for this calibration model to respond to other NMHCs as well as CH_4. As has been previously illustrated, these two VOC sensors exhibit different selectivities, thus including both may widen the range of VOCs that may elicit a response (Collier-Oxandale et al., 2019). Figure S5, available in the Supplemental Materials, highlights the differences between the single and multi-sensor models through their application to additional validation data collected during the field deployment period. Given that the amount of data available to directly compare the single and multi-sensor CH_4 calibration models in relation to both CH_4 and TNMHC reference data were limited (as a result of the available reference instrumentals at the different co-location sites), we were not able to conduct a thorough comparison of the two approaches for this dataset.

However, a better understanding of this issue would be valuable if these sensors continue to be used in the field.

As this study is exploring the potential for these sensors to indicate significant differences over small spatial and temporal scales, differences that may indicate the presence of local sources or phenomena worthy of further investigation, it's important to also consider similarities in the sensor signals. Table 4 displays the average intra-sensor coefficient of determination (R^2) and the average intra-sensor accuracy in the form of the RMSE. This data reveals high agreement amongst the sensors, which has been observed previously; for example, studies examining co-located MOx sensors have observed high correlation (Collier-Oxandale et al., 2018b; Cheadle et al., 2017; Sadighi et al., 2018). Furthermore, researchers studying the performance of eight Figaro TGS 2602 sensors found high intra-sensor correlation and relatively low variability amongst sensors when exposed to zero air, on the order of approximately +/− 5 ppb VOCs (Smith et al., 2017), which is similar to the average accuracy observed here for TNMHCs. Though, it is important to note that this test was performed over several hours and the results may vary over longer time scales of days or weeks.

Table 4:

Statistics for the Co-location Period

Target Pollutant	Intra-Device R^2	Intra-Device RMSE	S/R (Y-Pod)	S/R (Ref)
Single Sensor – CH_4 (ppm)	0.98	0.04	6.0	5.9
Multi-sensor – CH_4 (ppm)	0.98	0.03	6.8	5.9
Multi-sensor – TNMHC (ppb)	0.97	6.48	1.2	0.7

Table 4 also provides the signal to noise ratio (S/N) for the co-location period calculated as the median over the standard deviation (Piedrahita et al., 2014). Comparing the S/N values for the CH_4 estimates from low-cost sensor systems to the S/N values for the CH_4 reference data further emphasizes the agreement between the reference data and the fitted sensor data. It is more difficult to draw conclusions regarding the TNMHC S/N values, as the trends appear to be inherently noisier given that the S/N value for the reference data that is less than 1.0. Though when examining the timeseries data, excerpts from two separate days are shown in Figure 3, there are instances where increases in the fitted sensor signal coincides with increases in the reference data. There are also instances where an increase occurs in either the reference data or fitted sensor data that is not reflected by the other, however, it's worth noting that when increases occur in the fitted sensor data they are consistently reflected across all of the Y-Pods. The agreement in these trends suggests that what is driving the increases must be environmental as opposed to random noise, such as exposure to a target pollutant, a confounding compound, and/or a change in environmental conditions.

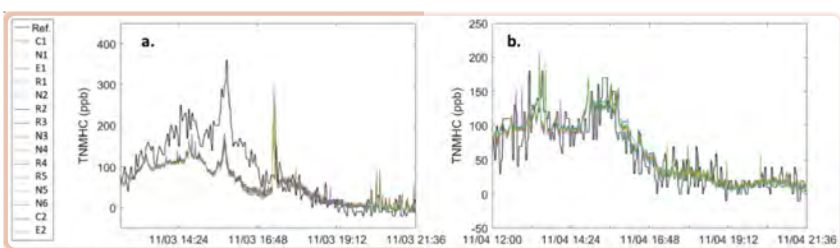

Figure 3:

Excerpts from the co-location period depicting reference data and fitted sensor data for TNMHCs.

Feedback

In terms of data completeness, there were periods of continuous data loss for two Y-Pods that do not appear to have impacted data quality, thus the available data from these Y-Pods has been included in the analysis. However, another a third Y-Pod experienced repeated, sporadic power loss resulting in unreliable data, and this Y-Pod has been excluded from the analysis. A fourth Y-Pod excluded from the analysis appears to have had a problem with a VOC sensor. The calibration model results utilizing data from this sensor were significantly different from the other results and this sensor exhibited poor correlation with other sensors of the same model. Thus, data from the remaining 14 Y-Pods were utilized in the analysis. Supplementary data from U-Pods co-located at certain field sites provided additional streams of data and that has also been included.

3.1.2. Additional Gas-Phase Sensor Quantification Results In addition to CH_4 and TNMHCs, the CO_2 and CO sensor signals were also quantified. Table 5 shows the summary statistics with the number of Y-Pods included. There are fewer CO sensors quantified as these sensors were not integrated into or co-located with all deployed Y-Pods. These uncertainties are similar to the results of other studies utilizing the same sensors in the same or similar platforms. For example, RMSEs of 10.1 ppm (Collier-Oxandale et al., 2018b) and standard errors of 9.4 – 16.8 ppm (Piedrahita et al., 2014) have been observed for this CO_2 sensor. While studies using this CO sensor have observed RMSEs of 0.10 ppm (Casey et al., 2018) and standard errors 0.28 – 0.44 ppm (Piedrahita et al., 2014). The statistics for each individual sensor and plots of the data are available in the Supplemental Materials (Tables S4 & S5; Figures S6 & S7).

Table 5:

Results of the generation and validation of models for the prediction of CO_2 and CO

	Training			*Testing*			
Target Pollutant	**R^2**	**RMSE**	**Mean Bias**	**R^2**	**RMSE**	**Mean Bias**	**Number of Y-Pods**
CO_2 (ppm)	0.91	7.72	−0.01	0.85	10.27	−4.43	15
CO (ppm)	0.88	0.088	0.0	0.87	0.05	0.01	5

3.2. Variability and Trends Captured by Sensors

Overall, the low-cost sensor systems reflect show similar temporal trends throughout the network, suggesting the presence of community-scale, or possibly regional patterns. Averaging both the CH_4 estimates and the TNMHCs estimates by hour of the day reveals elevated pollutant levels at night and lower levels during the day (Figure S8) – an expected diurnal pattern driven by fluctuations of the planetary boundary layer. The available reference CH_4 data, from site C1 and also plotted in Figure S8, reflects the same diurnal pattern as the sensor systems.

When the regional and local trends are separated using the baseline estimation technique described in Section 2.3.3 the agreement among the network sensors increases for the baseline datasets. This is illustrated in Table 6, which compares the average correlation coefficient for the complete dataset verses the baseline dataset between all sensor system pairs, sensor system pairs deployed in the same neighborhood, and sensor system pairs deployed in relatively close proximity (~ 140 m). Two trends emerge from these results: the first being that the correlation coefficients between baseline datasets are higher than for the complete datasets and the second being that the correlations tend to be higher for sensor systems that are closer together. The complete datasets include the short-term changes in pollutant levels that may be driven by local emissions or other phenomena, which are more likely to differ between sites than the diurnal/regional trends. Additionally, sites closer together are likely to have more shared influences in addition to being impacted more similarly by factors such as meteorology.

Table 6:

Average correlation coefficient (R) between Y-Pod baseline data across varying spatial scales

	Single Sensor CH_4		*Multi-sensor CH_4*		*Multi-sensor TNMHC*	
Scale	**Complete**	**Baseline**	**Complete**	**Baseline**	**Complete**	**Baseline**
All deployed sensors	0.70	0.72	0.72	0.76	0.60	0.59
Sensors within neighborhood	0.81	0.85	0.74	0.81	0.72	0.75
Sensors (E1 and E2, ~140 m apart)	0.93	0.99	0.86	0.95	0.87	0.97

Feedback

Given high level of agreement displayed by these sensor systems when they are co-located or amongst their estimated baseline signals, it stands to reason that when the pollutant levels estimated by these sensors vary the cause may be due to due to exposure to different pollutants, different pollutant mixtures, or differences in environmental factors (i.e., temperature of humidity). For example, a comparison of data collected during the co-location and during the field deployment, shown in Figure 4, reveals the variability that sensors can reflect when placed at different field sites approximately 140 m apart. Despite this close proximity, there are significant increases, well above the expected uncertainties of roughly 0.2 ppm and 50 ppb for CH_4 and TNMHCs respectively, that occur in both the correlated and uncorrelated data from these two field sites (Figure 4, in red). This data suggests that the sensors may be detecting phenomena that affect both sites simultaneously, that affect one site or the other, and that affect the two sites disproportionately. As this data results from models trained to estimate CH_4 and TNMHCs levels, these increases may be driven by exposure to these target pollutants, though we cannot rule out the influence of confounding pollutants or unexpected effects of environmental conditions. In either case, these sensors appear to be well-suited to identify unique trends that may be the result of small-scale spatial and temporal variability in pollutant concentrations.

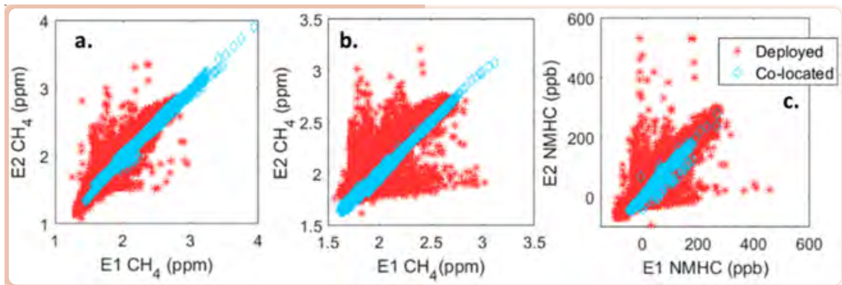

Figure 4:

Paired data for the two sampling sites near the drill site (E1 and E2), with co-located data plotted in blue and deployed data in red; using the a) single sensor CH_4, b) multi-sensor CH_4, and c) multi-sensor NMHC calibration models

3.3. Using Sensor Data to Characterize Potential Sources

While there remains a continual need to better understand the capabilities and limitations of low-cost sensors as well as how to improve data quality, leveraging multi-sensor systems and the comparability of sensors may be able to provide useful preliminary information. Using these networks, we can examine individual events potentially resulting from local emissions, we can study the spatial and temporal patterns across a network, or we can leverage different types of information to explore what a sensor network might suggest about the air quality throughout a community. The following analysis demonstrates these different approaches.

3.3.1. Examining Individual Air Quality Events

Short-term increases in pollutants or episodic events captured by low-cost sensors may be reflective of emissions from local sources. Here several apparent events have been selected to serve as examples of how we may be able to increase our understanding of these possible events. The periods shown in Figures 5 – 7 were selected as they depict increases in the estimated pollutant levels well above the expected uncertainties in addition to differing trends between two field sites that are relatively close together. These examples are not assumed to be representative of the datasets.

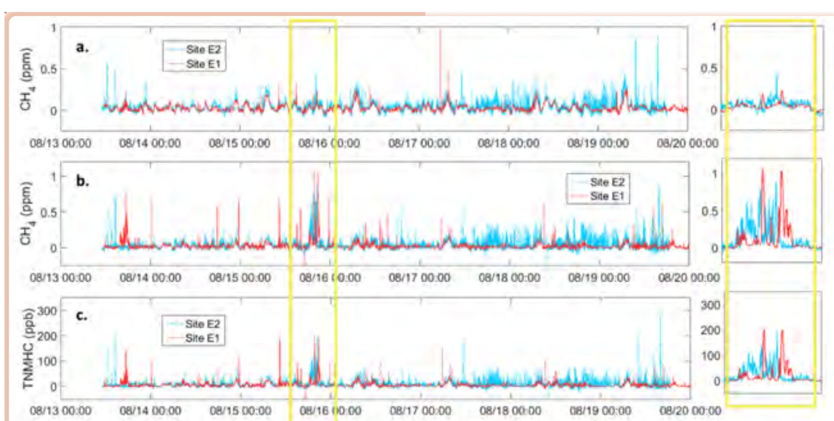

Figure 5:

Approximately one week of baseline-removed data, with panel a) including the single sensor CH_4 data, panel b) including the multi-sensor CH_4 data, and panel c) including the multi-sensor NMCH data. The time stamp is local, and the yellow box highlights the event discussed in the text. To the right of each panel is a zoomed in version of the event highlighted in yellow.

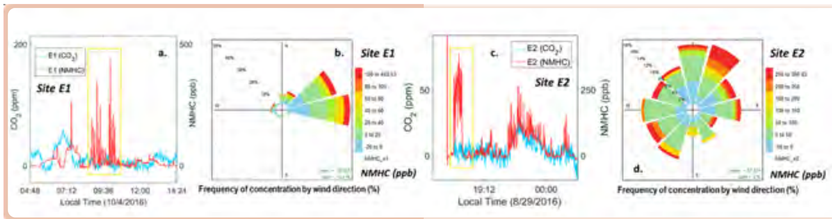

Figure 7:

Panels a) and c) include baseline-removed TNMHC and CO_2 data from Sites E1 and E2 respectively. Panels b) and d) depict pollution roses for the periods in panels a) and c) respectively.

The first event discussed is shown in Figure 5, which depicts baseline-removed data from sites E1 and E2, the two sites defined nearest the point source of interest identified by the community. This event is more well-defined in the two multi-sensor models, with changes in the estimated concentrations above the expected uncertainty of ~0.2 ppm for CH_4 and ~50 ppb for TNMHCs. The difference in predicted levels between the single and multi-sensor models for CH_4, as well as the levels predicted by the TNMHC model, may provide insight into the composition of the emissions. Previous research has demonstrated that the Figaro TGS 2602 appears to be responsive to heavier hydrocarbons, such as BTEX compounds, while the Figaro TGS 2600 is responsive to a range VOCs including lighter hydrocarbons, such as CH_4 (Collier-Oxandale et al., 2019). Though it is important to also consider the potential for known or unknown interferents to elicit a response from the sensors as well as environmental conditions unaccounted for by the calibration models.

Multi-sensor systems may provide greater insight into these responses by VOC sensors. In Figure 6, panel a, CO_2 and CO sensor data, from Site E2, have been added to the data shown in Figure 5. Both CO and CO_2 are combustion by-products and the lack of any significant or correlated response between the TNMHCs and CO_2 or CO suggests that the sensors' response to TNMHCs is more likely the result of volatilized or vented hydrocarbons as opposed to hydrocarbons from either complete or incomplete combustion. Additionally, these trends predicted by the VOC sensors are not driven by any obvious environmental conditions as they do not correlate with the data from the temperature or humidity signals (Figure S9).

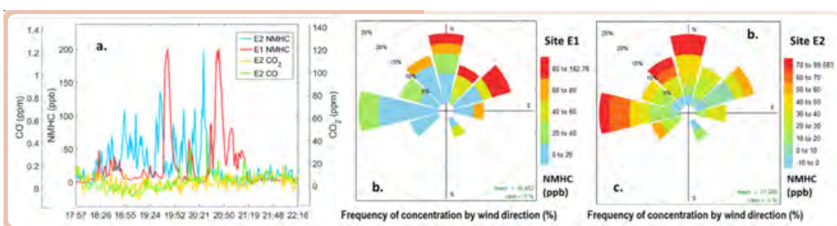

Figure 6:

Panel a) includes baseline-removed TNMHC, CO_2, and CO data from Site E2 as well as baseline-removed TNMHC data from Site E1. The data is from 8/15/16 and the times listed are local times. Panels b) and c) include pollution roses for the period of enhancements in TNMHCs for Sites E1 and E2 respectively, the data used to generate the pollution roses is from precisely the same time period depicted in panel a.

Meteorological data may also provide useful context to these measurements. The increases or possible episodic events at Sites E1 and E2 are not correlated and as indicated by the pollution roses in Figure 6, panels b and c, the increases do not appear to share a single origin. The increases at Site E1 appear to originate from the north/northeast and from the west/northwest for Site E2. As volatilized or evaporative hydrocarbons are emissions that may be associated with oil and gas activity (Moore et al., 2014; Warneke et al., 2014) and Site E1 is located to the west of the extraction site (<50 m) while Site E2 is to the east of the extraction site (<50 m), this analysis seems to suggest that the petroleum extraction site is one possible source of this emission event. As previously mentioned, there are no gas stations near these two sensor sites, however other potential sources of volatilized VOCs include a dry cleaner to the south of Site E1 (<100 m) and an auto repair shop to the southwest of E1 (<150 m). Further research using conventional measurement techniques would certainly be necessary to confirm the source of these emissions, but low-cost sensors may provide useful preliminary or indicative information in areas lacking current or historic data.

Feedback

Two additional examples are shown in Figure 7. During both periods, significant increases in TNMHC estimates occurred, independent of any response in the CO_2 data. Similar to the previous example, this difference in responses may suggest that volatilized hydrocarbons as opposed to those originating from combustion sources are responsible. Additional context is provided by the pollution roses, though in the case of the second example, in panels c and d, the likely origin of the elevations in the TNMHC estimations is less clear.

Figure 8 depicts periods of baseline-removed TNMHC and CO_2 data from sites directly adjacent to a major roadway. In all three panels, early morning, weekday hours are presented and increases in TNMHCs above the excepted uncertainty are observed. During the early morning hours, the planetary boundary layer is still low and facilitates the accumulation of pollutants; this condition combined with morning rush hour traffic may account for some of these increases. Furthermore, the TNMHC trends are well correlated with their respective CO_2 sensor trends as shown by the R^2 values in Table 7. This agreement between the sensor signals indicates that a combustion source or sources are likely responsible for these increases or potential episodic events.

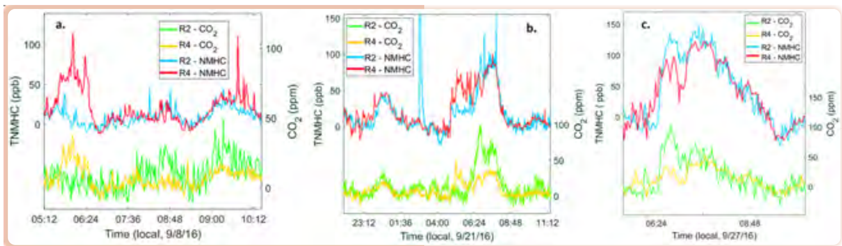

Figure 8:

Panels a – c) include baseline-removed TNMHC and CO_2 data from Sites R2 and R4 from three weekday mornings, during the deployment.

Table 7:

Coefficients of Determination between CO_2 and TNMHC signals for the events shown in Figure 8

	Panel A		***Panel B***		***Panel C***	
	R2 - CO_2	**R4 - CO_2**	**R2 - CO_2**	**R4 - CO_2**	**R2 - CO_2**	**R4 - CO_2**
R2 - NMHC	0.56	0.06	0.48	0.45	0.78	0.54
R4 - NMHC	0.01	0.68	0.39	0.81	0.71	0.89

In Figure 8 there are also several short-term increases in the TNMHC estimates that are not correlated with the CO_2 estimates indicating the possible presence of volatilized TNMHCs. Though these instances also reiterate the importance of considering additional information and datasets, like potential nearby sources and meteorological data as these responses may be the result of exposure to the target pollutants, known or unknown interferents, or a sudden change in environmental conditions. Considering the larger spatial and temporal patterns across a network can provide greater insight into responses by the sensor systems.

3.3.2. Identifying Temporal and Spatial Patterns Related to Local Air Quality Events

Examining patterns associated with short-term increases in the sensor responses may provide insights into where and when localized exposure events occur. In Figure 9 the complete data from four sites is sorted by hour of the day. Site R3 is above a busy roadway, Site N5 serves as a neighborhood site as it is in a predominantly residential area, approximately 250 m from the nearest highway, and approximately 950 m from the nearest petroleum extraction site. This site is also less than 100 m from an autobody shop and less than 400 m from several gas stations. The final two sites shown, E1 and E2, are again at the location of interest identified by the community. Similar box plots are available for each field site in the Supplemental Materials (Figures. S10 – S12).

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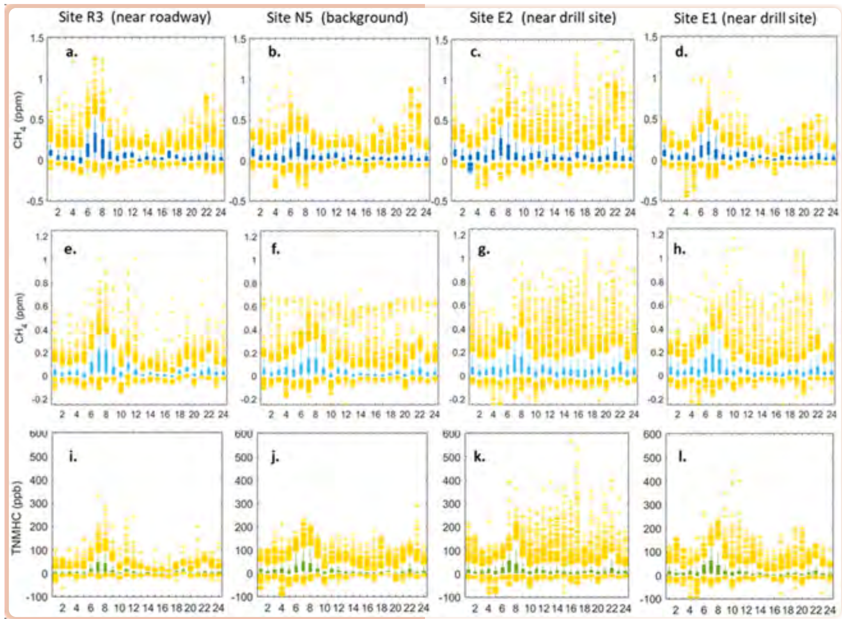

Figure 9

Baseline-removed data from four sites grouped by hour of the day (in local time), panels a-d) include the single sensor CH_4 data, panels e-h include the multi-sensor CH_4 data, and panels i-l) include the multi-sensor NMHC data. The whiskers on the box plots represent the 5^{th} and 95^{th} percentiles respectively. The top and bottom 5^{th} percent of the data are indicated by yellow markers across all plots.

Referencing data from other types of sensors, similar to the examples in Section 3.3.1, again reveals periods of agreement and disagreement between the sensor responses. The increases in the early morning and evening hours seen at the four sites in Figure 9 also appear in the CO_2 and CO sensor data shown in Figure 10. However, the increases in the late-morning and afternoon hours are not reflected in the data for these two pollutants. The timing of this pattern may provide insight into potential sources. Researchers studying the spatial variability of CH_4 determined that increases in ground level CH_4 can be indicative of sources up to 8.4 km away at night, but only 240 m away during the day (Bamberger et al., 2014). This study emphasized the ability of daytime mixing to disperse pollutants, suggesting that increases or episodic events observed during the afternoon are likely the result of relatively local sources as opposed to more distant sources. Thus, it is possible that the afternoon increases observed during this study are not only the results of a vented or volatilized source, but also the result of local emissions.

Across all four sites shown in Figure 9, elevated levels of CH_4 and TNMHCs occur during the early morning hours. This trend is likely driven by a combination of morning rush hour traffic and the lowered planetary boundary layer. Elevated concentrations during the night are also common to the sites; these are likely driven primarily by the lowering of the planetary boundary layer at night reducing dispersion. Regarding the early morning increases observed in the CH_4 estimates, this response is likely driven by interferents. Previous work has demonstrated that, in addition to various VOCs, the Figaro TGS 2600 is responsive to CO (Collier-Oxandale et al., 2018a & 2019); a pollutant that is likely to be associated with emissions from vehicles.

In addition to these expected diurnal patterns, there are also increases in the late-morning and afternoon, above the expected uncertainty for each pollutant, that are not consistent with expected traffic patterns and likely the result of a different source. In Figure 9, these increases or possible episodic events occur most prominently at site E2 and to a lesser extent at site E1. Similar trends are observed at other sites in the network as well, including N1 and N4 (Figures S10 – S12). For the four sites shown here, these repeated increases even result in elevated 95^{th} percentile values in the afternoon hours for Site E2 (Figure S13). Though the highest overall 95^{th} percentile value for TNMHCs occurs at site N4 (62.5 ppb), followed by site E2 (61.0 ppb), and then site N1 (59.7 ppb).

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3.3.3. Leveraging Sensor Networks to Learn More about Potential Sources in a Community

Together these patterns of how and when responses are observed from multi-sensor devices provide useful information about local air quality patterns. Figure 11 provides information for the whole network, depicting the baseline-removed CO_2 and TNMHC data, colored by the hour of the day, for each sensor system. Similar plots are available for CO and TNMHCs and CO and CO_2 (Figures S14 – S15). A reference ratio has also been added to the second set of plots that represent the expected $CO:CO_2$ ratio based on the CARB emission inventory for the South California Air Basin as observed during aircraft measurements (Peischl et al., 2013). This additional information illustrates how the observation drawn from the CO and CO_2 sensors appear to be in agreement with expected trends and previous studies.

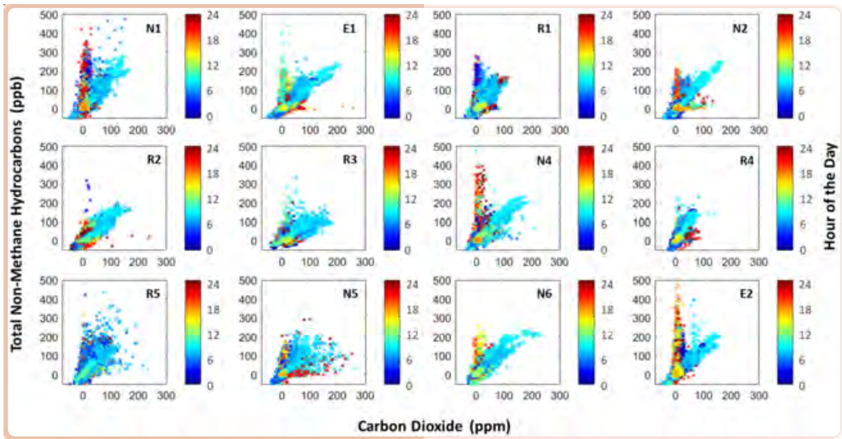

Figure 11:

Scatterplots of baseline-removed data CO_2 and TNMHC data for sites in the deployment area, with the color indicating the hour of the day in local time.

The patterns in Figure 11 again suggest that the sensors may be responding to hydrocarbons from both vented or volatilized sources and combustion sources. At sites N1, N4, and E2 there are relatively large increases in hydrocarbons, reaching levels greater than five times the expected uncertainty, and independent of any apparent increase in CO_2. As these plots depict the baseline-removed data, these increases are likely to be short-term events as opposed to the result of regional or diurnal pollutant trends. Whether these sensors are responding to the target pollutants, interferents, or a mixture, the dramatic differences in patterns between these three sites and the other sites may warrant further investigation with more conventional sampling techniques. There are also interesting differences amongst sites where TNMHCs and CO_2 seem to be positively related. For example, at some sites the two pollutants are correlated along a more consistent ratio (e.g., N2 or R2), while at other sites there appear to be more varied relationships between the two pollutants (e.g., N5 or R5). One explanation for this difference could be the presence of more similar verses more varied combustion sources. Site R5 was located at a garage where maintenance vehicles were kept, and a wider array of gasoline and heavy-duty vehicles entering and leaving the facility might account for the larger variance in the TNMHC:CO_2 ratio.

In Figure 12, the concentration estimates for CH_4 and CO are included to provide further insight into these increases or possible events. Similar to Figure 11, there are increases in estimated CH_4 during the afternoon and early evening hours at site E2 that occur independent of any apparent increase in CO. Alternatively, at site R4 there do not appear to be any increases in CH_4 that are independent of increases in CO. This example confirms that while one of the VOC sensors used is cross-sensitive to CO the presence of CO does not account for at least some of the observed increases at site E2. This also further supports the assertion that one or more local non-combustion source (i.e., not from traffic or vehicle exhaust) may be contributing to elevated hydrocarbon levels at this site. Though the calibration model is trained to estimate CH_4, these non-combustion elevations may be driven by other VOCs, a mixture, or possibly other interferents. In terms of the varied and distinct ratios observed between the CH_4 and TNMHC estimates, these may indicate the presence of different VOCs or different VOC mixtures and certain ratios may even be associated with specific sources (Collier-Oxandale, et al., 2019). The ability to measure CH_4 may be especially valuable for community-based air quality monitoring as this compound may be able to serve as a marker for certain source types, such as sources associated with oil and gas development.

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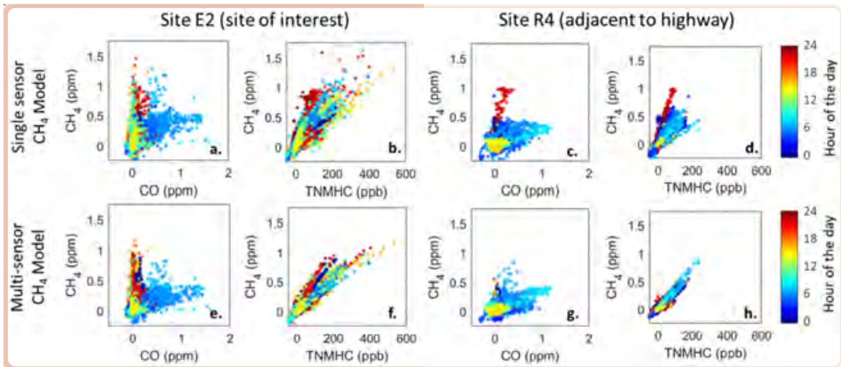

Figure 12:

Scatterplots of baseline-removed data CO or TNMHC data versus CH_4 data from two sites in the deployment area (E2 and R4). Note the CH_4 on the top row was converted using the single-sensor calibration model and the CH_4 values in the bottom row were converted using the multi-sensor calibration model. The color indicates the hour of the day in local time.

Figure 13 summarizes the spatial variability demonstrated by the previous analysis with each map depicting the average TNMHC:CO_2 ratio for a given time of day (i.e., the morning hours, afternoon hours, and evening hours). The ratios are lower and more similar in the morning hours, but exhibit more variability during the afternoon and evening hours. At sites R2 and R4, directly adjacent to a major roadway, the ratios do not increase that dramatically. By comparison there are several neighborhood sites, such as E2 (circled in yellow in Figure 13), where the short-term increases observed in the baseline-removed data result in higher averages. Using this type of approach to leverage the information available from a dense network of multi-sensor devices could be a way to characterize an area and provide preliminary information regarding potential sources or anomalies in local trends.

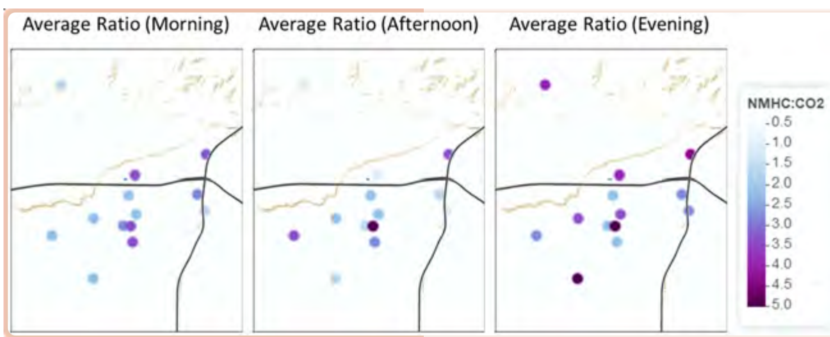

Figure 13:

Three maps of the average TNMHC:CO_2 ratio at each site in ppb/ppm for the baseline removed data sets. The map to the left, for the morning hours, depicts the average for 6 – 9am. The middle map depicts afternoon hours from 12 –3pm. The map to the right, depicts evening hours from 5 – 8pm.

3.4. Leveraging Sensor Data to Understand Resident Experiences

Given the accessibility of low-cost sensor systems, it is likely that communities concerned about their local air quality will be interested in using this technology to better understand their local environment. If sensor systems are leveraged appropriately, with communication of sensor limitations and careful interpretation of sensor data, this may be accomplished. For example, sensor networks may be able to help identify the locations of "hotspots" or recurring episodic events, which could then be compared to residents' observations. In this type of application, sensor data may be able to provide compelling evidence that sources of concern are worthy of further investigations. It is also possible that a sensor may not be able to detect a particular source or that a sensor may reflect relatively low emissions from a source. In all of these cases, sensor data has the potential to provide new information to facilitate further investigation, a new approach to that investigation, or informed action with the aim of improving community health.

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Having examined the low-cost sensor data, we wished to consider how this data related to observations from community residents.

As described previously, our community partners provided observational information from residents living near the petroleum extraction site. To begin, the sensor data was examined for potential air quality events corresponding to that observational data; several examples are shown in Figure 14. Many of these examples include increases in TNMHC estimates that are independent of significant changes in CO_2, possibly indicating a volatilized or vented source

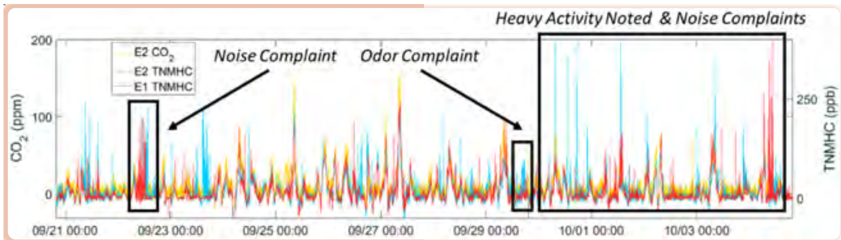

Figure 14:

Baseline-removed CO_2 and TNMHC data from Site E2 and Site E1, annotated with noise and odor complaints as well as observations by residents of heavy activity at the drill site.

While this is not conclusive, as there are several peaks in the measured concentration that do not coincide with residents' observations, this dataset provides a unique opportunity to pilot ways to access and compare the information available in these two distinct datasets. One approach is demonstrated in Tables 8 and 9, where the data has been summarized using a confusion matrix. In this matrix, this study has been sorted into days where both an observation and an increase in estimated pollutant levels occurred, days where one or the other occurred, or days where neither occurred. In this example analysis a "peak" is defined as increase in estimated TNMHCs greater than 100 ppb in the baseline-removed data, and given the frequency of the peaks, days on which more than three occurred were used for this comparison. Table 8 compares the resident observations with data from the two nearby sampling sites and Table 9 compares these observations with data from sites further away.

Table 8:

Confusion matrix comparing resident observations and the occurrence of peaks at sites E1 and E2

	Observation Noted	**No Observation Noted**
Peaks Noted (>= 3 per day)	26	16
Few Peaks Noted (< 3 per day)	3	10
Rates	True Pos. = 0.90	False Pos. = 0.62
	False Neg. = 0.10	True Neg.= 0.38

Table 9:

Confusion matrix comparing resident observations and the occurrence of peaks at sites R3 and N4

	Observation Noted	**No Observation Noted**
Peaks Noted (>= 3 per day)	15	5
Few Peaks Noted (< 3 per day)	14	21
Rates	True Pos. = 0.52	False Pos.= 0.19
	False Neg. = 0.48	True Neg. = 0.81

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In general, more peaks appear to have occurred at sites E1 and E2 as compared to sites R3 and R4. Comparing Tables 8 and 9, a higher rate or both true positive results and false positive results was seen when comparing residents' observations to data from the nearby sites. Though false positive results could be explained by peaks that occur when residents are away from home or asleep. Additionally, a higher rate of false negative results occurred when comparing the residents' observations to the data from far sites. This initial analysis seems to indicate greater agreement between the residents' observations and sensor data collected at the nearby sampling sites.

Ways to improve this type of analysis would include conducting a more comprehensive data collection from residents living throughout the area of the sensor network, systematically comparing data from many residents to sensor data throughout the network and testing different ways of defining peaks and responses in the sensor data. Particularly in high density areas with many sources, like Los Angeles, there is the potential for sensor data to support a better understanding of local air quality as well as the potential for observational information to provide additional context to the air quality trends observed and their impacts on nearby populations. While additional considerations around how to collect and interpret this observational information or local knowledge are necessary, it is possible that leveraging these two types of information could facilitate more participatory and inclusive studies; while also enhancing data interpretation leading to more locally relevant and actionable results for a community.

4. CONCLUSION

In line with previous research utilizing the same VOC sensors, the results of sensor performance quantification were similar to expected results and the converted sensor data reflected expected environmental trends – specifically regional and diurnal trends (Collier-Oxandale et al., 2018a & 2019). This network also provides new information by revealing short-term or episodic enhancements over background in CH_4 and TNMHC concentrations that are likely the result of local emission events given the time of day at which many of them occur. Incorporating the CO_2 and CO sensor data from the same time periods seems to suggest that some of these increases were the result of volatilized or vented hydrocarbons, as opposed to a combustion source. For the location of interest (near sites E1 and E2), some of these increases even coincide with observations made by nearby residents concerning odors or activity at the petroleum extraction facility. While these results are not conclusive, particularly given the limitations of low-cost sensors, they seem to indicate that combustion sources, such as traffic, are not the only source of hydrocarbons having a measurable impact on air quality in this community. These results also demonstrate how multi-pollutant sensor networks may be able to help meet the desire for more air quality data at the neighborhood-level. We used this approach to distinguish between emissions originating from different sources-types within a community, and we hope that others continue to build on this work – leading to more locally relevant information for communities that can support actions to improve public health and reduce disparities in exposure.

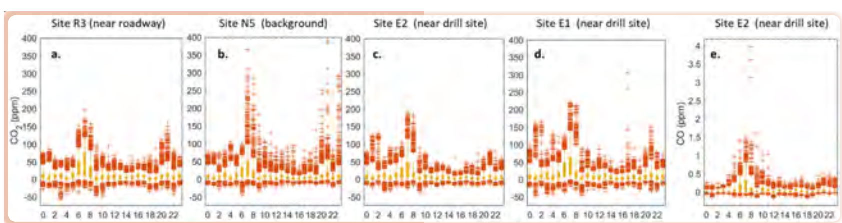

Figure 10:

Baseline-removed data from four sites grouped by hour of the day (in local time), panels a-d include CO_2 data, and panel e includes the CO data collected at site E2.

Supplementary Material

Supplementary Material

Click here to view. (3.6M, docx)

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Footnotes

Note 1: (regarding reference air quality data) this data has not passed through the normal review process and is therefore not QA/QC'd and is unofficial data.

Note 2: (regarding the first author's current position with the South Coast Air Quality Management District): this is a research article and does not constitute an endorsement or recommendation of a particular low-cost sensor or low-cost sensor platform.

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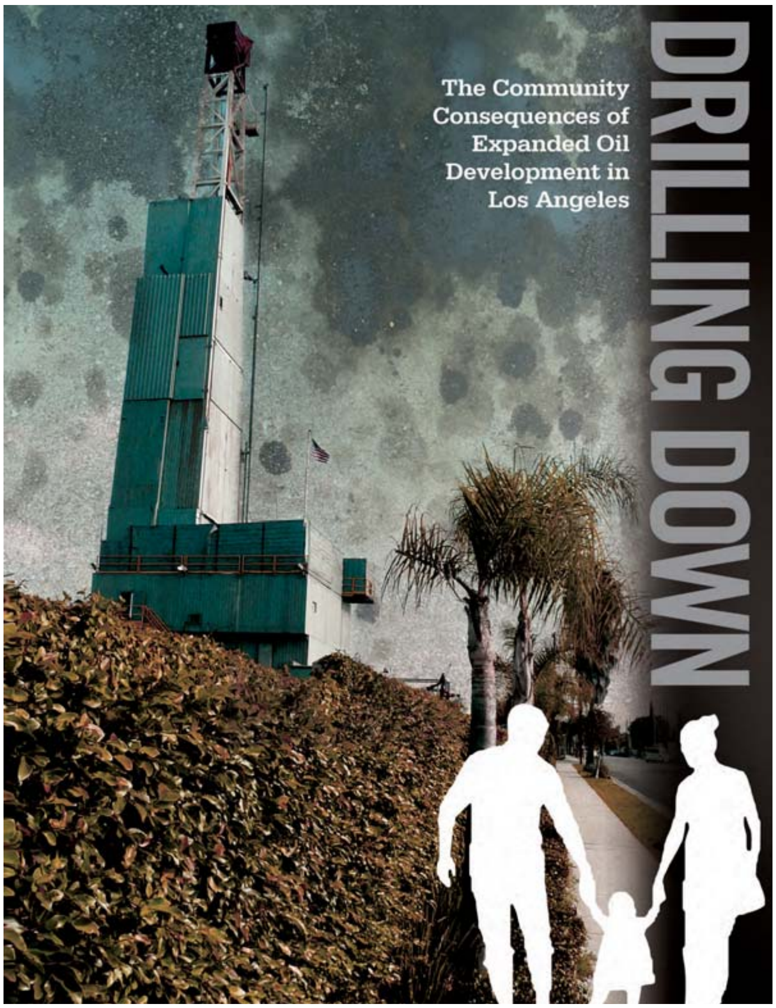
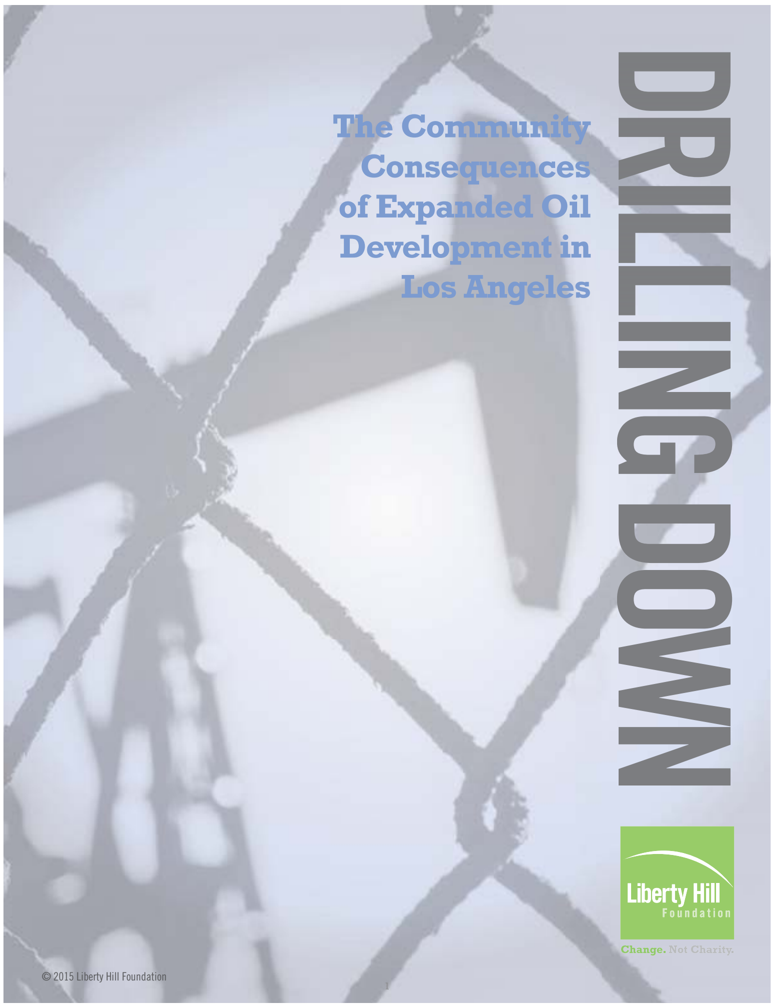
Feedback

Exhibit 3 of 13 - Drilling Down Report 2015



This publication is dedicated to the memory of Lark Galloway-Gilliam, founder and executive director of Community Health Councils, and a fearless leader who devoted her life to the fight for equality, health and justice for all.



DRILLING DOWN

The Community Consequences of Expanded Oil Development in Los Angeles

Liberty Hill Foundation

Change. Not Charity.

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Ashley Hernandez, Wilmington resident

An oil drilling site operated by Warren E&P encroaches upon a residential neighborhood in Wilmington.

INTRODUCTION

Oil drilling operations loom over many residential neighborhoods in Los Angeles.

From South Los Angeles to Baldwin Hills to the Harbor area, neighborhoods throughout Los Angeles are on the frontline of an epic debate about our energy future.

This report shares stories of residents who are living very close to oil drilling and production operations where toxic chemicals and potentially hazardous well stimulation technologies are used to extract oil from the ground.

Mothers, fathers, senior citizens, and students all share their experiences of exacerbated health ailments—including nosebleeds, nausea, respiratory illness, and dizziness—that they believe are associated with oil development operations in their neighborhoods. They detail their growing concerns with disruptive diesel trucks rumbling past their homes, noxious odors, escalating noise levels, and an unsettling fear of the potential for explosions, spills, and other hazardous incidents.

In this report, we also highlight residents' accounts of a fragmented and ineffective regulatory and zoning system. Unresponsive government agencies, local authorities, and energy company public relations have all too often failed to be transparent and provide notification, and have ignored, delayed, or denied that residents' concerns are real and urgent.

While Los Angeles has been a center of oil production for decades, this report reveals that many more people are now living in neighborhoods where years ago oil companies received their drilling permits. Today, we find densely populated urban neighborhoods with homes, schools, daycare centers, and multifamily and senior apartment buildings adjacent to expanding oil and gas operations.

We also find that most of the neighborhoods featured in this report are typical "environmental justice" (EJ) communities where residents already suffer disproportionately from exposure to air toxics that are associated with elevated rates of asthma, respiratory and heart diseases, and cancer than do higher income and majority Anglo neighborhoods. The neighborhoods and corresponding drill sites profiled here include: University Park, Jefferson and Murphy Drill Sites in Historic West Adams, Wilmington and Baldwin Hills.

With ***DRILLING DOWN: The Community Consequences of Expanded Oil Development in Los Angeles***, Liberty Hill Foundation aims to contribute to the current policy debate. Should the City and County of Los Angeles pass moratoriums on enhanced forms of energy production or consider additional health-protective standards, such as distance buffers or prohibitions next to sensitive land uses? How can government create full transparency and accountability to our residents when multiple jurisdictions regulate oil drilling sites? And, with an eye to the future, does Los Angeles want to increase our investment and dependence on dirty, fossil fuel infrastructure—or accelerate our movement toward renewable energy that will improve environmental health, reduce carbon emissions, and increase the potential for a massive expansion of jobs in the fields of energy conservation, energy efficiency, and renewable energy technology?

By highlighting the voices of community residents, our goal is to urge decision makers to move toward a vision that prevents premature death and illness from environmental causes and that supports a healthy, safe, and sustainable Los Angeles.

The neighborhoods at the frontlines—and all Angelenos—deserve such a future.

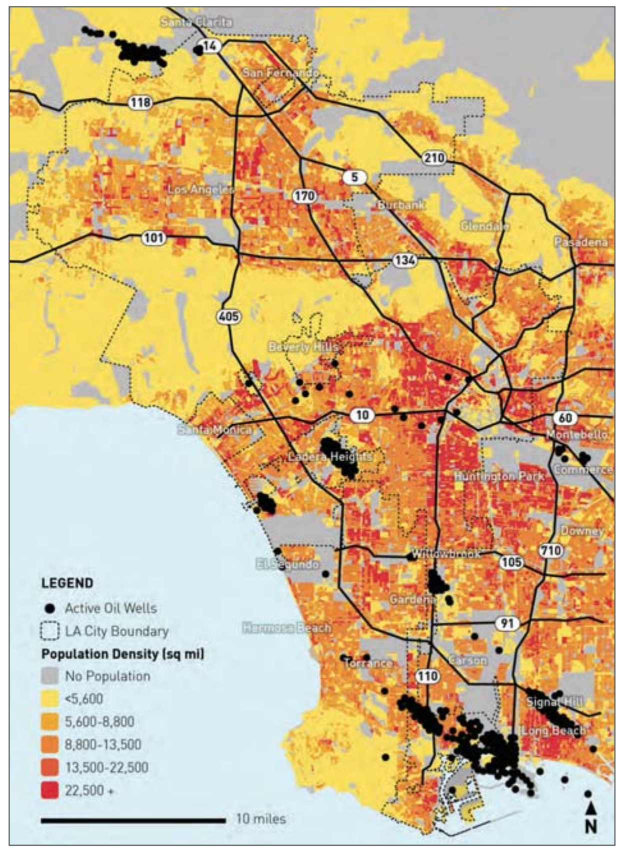
Michele Prichard
Director, Common Agenda

Daniela Simunovic
Environmental Health and Justice Program Manager

Fall 2015

Liberty Hill
Change. Not Charity.

MAP 1: Active Oil Wells in Los Angeles County and their Relationship to Population Density



Many oil wells and fields are located in areas of high population, exposing large numbers of people to the hazards associated with these facilities and their operations.

(Data from 2010 US Census and Department of Oil, Gas, and Geothermal Resouces 2014)

OIL EXTRACTION IN LOS ANGELES: HEALTH, LAND USE, AND ENVIRONMENTAL JUSTICE CONSEQUENCES

James Sadd, Ph.D., *Professor, Environmental Science, Occidental College*
Bhavna Shamasunder Ph.D., *Assistant Professor, Urban and Environmental Policy, Occidental College*

Los Angeles is the largest urban oil field in the country. Thousands of active oil wells in the greater Los Angeles area are located near and among a dense population of more than 10 million people. In some cases, oil drilling and production are located disturbingly close to homes, schools, churches, urban parks and playgrounds, and hospitals[1] —places where our communities live, work, go to school, and play. These areas are identified as "sensitive land uses" because populations that are biologically sensitive[2] to air pollution and cancer-causing chemicals—the very young and the elderly, and people with respiratory disease—spend extended time in them each day[3]. Many active wells are also located within environmental justice neighborhoods, as defined by state law[4] and identified by the California Environmental Protection Agency (CalEPA). These neighborhoods are characterized by residential populations with high proportions of the poor and unemployed, persons with low educational attainment, a high percentage of non-English speakers, high levels of certain health impacts (low birth-weight infants, asthma), and people who also experience greater exposure to environmental hazards and the attendant health risks, as compared to the general population.

History of Oil Production and Land Use

The juxtaposition of oil production near communities is a consequence of the history of oil exploration and drilling in Los Angeles and poor land use decision-making. Early in its history, Los Angeles was a slowly growing agricultural region. However, early in the 20th century, three driving forces—the production and use of petroleum, the import and use of water, and a rapidly expanding transportation network—set into motion the growth and change that created the Los Angeles of today. For a brief period in the 1930s, the city was the center of world oil production and the Los Angeles basin was the Saudi Arabia of the day (Tygiel 1996). After the discovery of oil near today's Dodger Stadium at a depth of only 460 feet, discoveries of major oil fields quickly followed at Huntington Beach, Signal Hill (Long Beach), and Santa Fe Springs, as well as many smaller fields with names that define the heart of the city itself: Los Angeles, Union Station, Boyle Heights, Downtown, Las Cienegas, Inglewood, Playa del Rey, Venice, Sawtelle, San Vicente, Rosecrans, and Wilmington. Oil transformed the region's economy and repurposed its growth and development.

For decades, the petroleum industry became the leading sector of the entire state's economy, with California supplying about a quarter of the world's oil and gas. The industry reached its peak in the late 1960s, exporting approximately 133 million barrels of oil per year. An enormous amount of money was quickly made from oil in Los Angeles and spent in extravagant ways. Oil money created family dynasties with names like Getty, Doheny, and Bell; funded huge real estate developments; and made possible the network of roads and highways that ushered in reliance on cars requiring a constant supply of gasoline. Hollywood and the motion picture industry were also significantly financed by the new

[1] These specific land uses have been identified by the California Air Resources Board (CARB 2005).
[2] Sensitive Populations are defined by the CalEPA to include schools, daycare centers, senior residential facilities, urban parks and playgrounds, and healthcare facilities (CARB 2005).
[3] Sensitive Land Uses are defined for purposes of health protection from air pollution by the California Air Resources Board (CARB 2005).
[4] California Government Code 65040.12e

Almost one quarter of active wells in the city are located on residentially zoned land (mostly multifamily and high density).

oil economy (*New York Times* 2008). In addition to oil, the Los Angeles Aqueduct brought surplus water to the region, and the Los Angeles Flood Control District installed systems to alleviate the region from disastrous and destructive flooding. This allowed the population to increase rapidly, and by the late 1930s, the agricultural economy was completely replaced with residential land, and a manufacturing and commercial economic base. Today, oil wells across the greater Los Angeles area remain very productive, yielding approximately 28 million barrels per year from fields on land as well as offshore.

The Geographic Distribution of Oil Production

The California Division of Oil, Gas, and Geothermal Resources Division (DOGGR) is the primary public agency responsible for oversight of petroleum-related activities, including pollution emissions prevention[5] and public safety, and it maintains an extensive well inventory that is publically accessible[6]. According to DOGGR, there are well over 24,000 wells in L.A. County, mostly concentrated in about 70 oil fields (Chilingar and Endres 2005). Some 5,194 of these wells are either "new" (356) or "active" (4,838) as of 2014. According to the City of Los Angeles Department of City Planning, the city hosts 1,071 new and active oil wells located in a few specific areas (see Map 1), with the most dense concentrations in established oilfields. About half of the city's active wells are located in the Wilmington area and most of the rest are in isolated fields in West L.A., South L.A., and Mid-City neighborhoods. Three quarters of the active wells in the city are operated by five companies[7].

Los Angeles is unusual in that it is a densely populated major city with many active oil production facilities located in close proximity to communities and residences. In some places, oil production takes place just over a fence line or on the same block as homes, schools, and vulnerable populations. Additional oil wells located outside the city boundaries are also in close proximity to residential neighborhoods in Beverly Hills, Baldwin Hills, Inglewood, Marina del Rey, and El Segundo. The oil industry has responded to this proximity and population density by employing horizontal wells and directional drilling, which enables them to access oil over a wide area from a tightly concentrated central facility that is often hidden by fences, hedges, walls, and even camouflage (Center for Land Use Interpretation 2010).

Beyond oil extraction, there is a vast network of facilities supporting the chain of oil production, transport, refining, and distribution. Marine terminals in the Ports of Los Angeles and Long Beach receive and store nearly all of the region's crude oil, tar sand, and asphalt. Transportation of oil, natural gas, and refined product is concentrated along pipeline routes, along with the network of rail and trucking routes that distribute the product to users. Eleven of the top 20 petroleum refining facilities statewide are located in the Los Angeles area, almost all of which are in a narrow belt from Long Beach to El Segundo, and together the refineries process over one million barrels per day (California Energy Commission 2012). Because of the high demand from its large and dense population, and because there are no pipelines linking local refineries to other states, nearly all the gasoline and diesel fuel used in this region is produced locally.

5,194	Number of active oil wells in the County of Los Angeles
70%	Percentage of active oil wells in City of Los Angeles located within 1,500 feet of a home or sensitive land use such as a school or hospital
50%+	Percentage of census tracts in L.A. County (many of them close to active oil wells) that ALREADY rank in the state's top 20% of most environmentally polluted and socially vulnerable areas according to CalEnviroScreen
280-400 GALLONS	Amount of wastewater produced for every barrel of crude oil extracted
WORST IN THE U.S.	Rating by the American Lung Association of L.A.'s air pollution from ozone, also known as "smog." Oil production has been linked to increased smog levels

Methods of Oil Extraction

The Los Angeles basin is the most petroleum-dense basin in the world (Signal Hill Petroleum 2014). In the 1980s and 1990s, as the price of oil dropped and property values rose, oil wells around Los Angeles were capped and oil production fell (Gamache and Frost 2003). Today, the Los Angeles basin is witnessing a resurgence in oil production as old

[5] Additional oversight is provided by the California Air Resources Board and the California State Water Resources Control Board, as well as local jurisdictions.
[6] http://www.conservation.ca.gov/dog/Online_Data/Pages/Index.aspx
[7] These five companies include Plains Exploration & Production (25.1%), Tidelands Oil Production (16.9%), Warren Exploration & Production (16.9%), Brea Canon Oil (7.8%), Southern California Gas Company (7.6%).

The oil and gas industry in the United States creates more solid and liquid waste than all other categories of municipal, agricultural, mining, and industrial wastes combined.

wells are uncapped, new wells are drilled, and the industry is actively working to pull more oil out of the ground within an even more populous city. Nationally, as oil has been depleted from conventional geologic formations, the oil industry has pursued "unconventional oil," defined as "resources that are deeper or more difficult to recover than those that have been recovered historically" (U.S. Environmental Protection Agency 2008). However, Los Angeles still contains large quantities of migrated oil that are extracted using a combination of conventional drilling, Enhanced Oil Recovery (EOR) and unconventional technologies. Only 10 percent of a reservoir's oil can be recovered by conventional practices. The rest must be accessed through ramped-up methods using EOR techniques that include injecting steam, gas, and/or chemicals to produce more oil from a well. These techniques are employed after easy-to-produce oil has already been recovered (U.S. Department of Energy 2014).

Los Angeles has also seen the introduction of some unconventional drilling techniques, such as acidizing and hydraulic fracturing. Unconventional drilling practices include the use of long-range and directional drilling to vertically drill thousands of feet below the surface and then directionally (horizontally) for up to two miles, though in California this distance tends to typically be tens to hundreds of feet away from a well (DOGGR 2013). While directional drilling technologies are typically used to pull difficult-to-access oil in tight geologic formations, in Los Angeles these more aggressive technologies are used to access oil pools that are farther away from a well pad, to circumvent restrictions on creating new well pads and to avoid the social and political ramifications of extracting oil from dense residential neighborhoods through more conventional methods.

In Los Angeles, these technologies are employed to extract oil from small areas and densely populated neighborhoods, with the community just outside the fence line. Thousands of barrels of oil are extracted from wells that can be across the street or next door to a residence.

Environmental and Toxic Chemical Impacts

The oil and gas industry in the United States creates more solid and liquid waste than all other categories of municipal, agricultural, mining, and industrial wastes combined (O'Rourke and Connolly 2003). The industry

KEY DEFINITIONS FOR OIL DRILLING & PRODUCTION

Directional Drilling	The drilling of non-vertical wells (U.S. Environmental Protection Agency 2010).
Enhanced Oil Recovery	Various methods used with mature wells to increase oil and gas production. Includes injection of water, steam, gas and/or chemicals down the well and into the subsurface toimprove flow and help push the petroleum to the surface.
Acidizing	Used in sites across Los Angeles. Often referred to as matrix acidizing, thousands of pounds of acid are injected into wells, where they dissolve the sediments, allowing the oil to flow to the wellhead to be collected. Both hydrofluoric acid and hydrochloric acid are used in these operations. These acids are so corrosive that other chemicals are added to the mixture to ensure the acids dissolve only the intended rock formations rather than the steel casings used to drill the well.
Steam Injection	Used in the Wilmington Oil fields. It is an enhanced oil recovery method injecting very hot steam into wells to extract deeper, heavier (and dirtier) crude.
Water Flooding	A type of enhanced oil recovery in which water is injected into a formation in order to mechanically move heavy oil from one well to another to be collected. Water flooding is used in many oil fields in the L.A. basin.
Gravel Packing	Method used to hinder the introduction of sand into the oil being produced, which damages oil field hardware. The zone surrounding the well bore is packed with gravel, which acts as a filter to prevent sand entering the well. Gravel packing stabilizes the surrounding rock, and is typically used in hydraulic fracking. (Sanchez and Tibbles 2007).

Exposure to ozone is linked to problems including the triggering of asthma attacks, an increase in emergency room visits, decrease in lung function, and premature death.

emits chemicals such as benzene, toluene, xylene, formaldehyde, and nitrogen oxides—to name a few—and has been implicated in exposure through air, water, and soil (Shonkoff, Hays, and Finkel 2014).

Oil extraction is a water-intensive activity. After a well is stimulated, some of the volume of fluid returns to the surface. This wastewater is a combination of stimulation fluids (often termed "flowback") and "produced water," which is extracted from the ground along with the oil. "Produced water" can be reinjected into wells under high pressure to force more oil to the surface, or reinjected into the formation to maintain pressure, or it can be sent to disposal wells. "Flowback" contains many chemical additives known to be harmful to health that are included in the injected stimulation, and "produced water" can be contaminated with byproducts from drilling, such as volatile organic compounds and heavy metals. On average, about 280-400 gallons of water (7-10 barrels) are produced for every barrel of crude oil extracted (U.S. Department of the Interior, Bureau of Reclamation 2011).

Oil drilling practices such as acidizing and hydraulic fracturing rely on a mixture of chemicals that are injected into wells. These can include surfactants, solvents, and corrosion inhibitors, some of which are known carcinogens, reproductive toxins, and endocrine disruptors[8]. For example, one study of wells stimulated through hydraulic fracturing in Colorado identified 944 products used in natural gas drilling and could find toxicity data for only 353 of these. Of these 353, the study found that more than 75% could affect the skin, eyes, and other sensory organs; 40-50% could affect nervous, immune, and cardiovascular systems; 37% could affect the endocrine system; and 25% could cause cancer and mutations. This study points to the problem of lack of disclosure of chemicals used in these processes and the need for full disclosure of all chemicals used in drilling. It also points to the need for air and water monitoring and coordinated human and environmental health studies (Colborn, Kwiatkowski, Schultz, and Bachran 2011).

In Los Angeles, a report by a coalition of environmental justice and environmental organizations based on new disclosure requirements by the South Coast Air Quality Management District (SCAQMD) examined chemicals that were released from event reports filed since June 2013 (Physicians for Social Responsibility et al. 2014). These include 170 acidizing, 95 gravel-packing, and 11 hydraulic-fracturing events.

Chemical reporting by operators in the SCAQMD set includes air toxics such as crystalline silica, methanol, hydrochloric acid, hydrofluoric acid, 2-butoxy ethanol, ethyl glycol, xylene, amorphous silica fume, aluminum oxide, acrylic polymer, acetophenone, and ethylbenzene. Chemicals listed include known carcinogens, reproductive toxins, endocrine disruptors, and mutagens. However, the full extent of the use of these chemicals is unknown, since companies can withhold chemical identities and mixtures under "trade secret" protections (Air Quality Management District 2013).

Air Toxics and Human Health Hazards

Oil drilling, extraction, and development is associated with a variety of health-damaging air pollutants (Helmig et al. 2014). Air pollution is linked to many adverse health outcomes such as asthma, exacerbated heart disease, and low birth weight (Peden 2002; Wilhelm and Ritz 2005). As oil production has increased, residents in Los Angeles communities living near oil wells routinely report symptoms of dizziness, nosebleeds, headaches, and exacerbated asthma (Sahagun 2013). Corroborating on-the-ground experiences, there is a growing literature linking unconventional oil and gas drilling with increased air pollution, water contamination, noise pollution, and stress (e.g., Adgate, Goldstein, and McKenzie 2014; Helmig et al. 2014; Shonkoff, Hays, and Finkel 2014). Environmental justice communities face a "double jeopardy" from air pollution that can compound the effects of already high exposures to environmental hazards.

These communities often suffer from the cumulative effects of poverty, lack of access to adequate health care, and illnesses that can leave individuals more vulnerable to the toxic effects of pollution (Morello-Frosch et al. 2011). In the Los Angeles area, poor air quality is an ongoing problem for low-income communities of color, who are disproportionately exposed to air toxics from industry, goods movement, and autos on a vast network of highways and roads (Sadd et al. 2011). The oil industry is the largest industrial source of volatile organic compound (VOC) emissions, a group of chemicals that contribute to smog and ground-level ozone (EPA, 2014), which make up the primary components of Los Angeles smog. In 2008, the EPA estimated that VOC emissions from the oil and natural gas industry exceeded 2.2 million tons per year, data that has not been updated since the boom in oil and natural gas production over the past few years (EPA 2014). Exposure to ozone is linked to problems including

[8] Endocrine-disrupting compounds disrupt the body's hormone systems. This can happen at very low levels of exposure and exposures are especially concerning during vulnerable stages of human development (such as the fetal stage), which can lead to irreversible health problems even decades after an exposure (Zoeller et al. 2012). Most of these compounds remain unregulated and those that are regulated have thresholds far above those at which endocrine disruptors can cause harm.

the triggering of asthma attacks, an increase in emergency room visits, decrease in lung function, and premature death (Jerrett et al. 2005; McConnell et al. 2010). Los Angeles already has the worst ozone pollution in the United States (American Lung Association 2014).

States that have expanded drilling operations have documented elevated levels of VOCs and worsening ozone levels in areas near drilling operations, and they have called for buffer zones, setbacks, and continual air-quality monitoring near oil and gas fields, concluding that "there is a strong causal link between oil and gas emissions, accumulation of air toxics, and significant production of ozone in the atmospheric layer." (Edwards et al. 2014; Olaguer 2012).

Particulate matter is composed of very small particles that can move deep into the lungs and enter the bloodstream, and can contribute to heart problems, lung cancer, respiratory illness, and premature death. Sensitive populations such as fetuses, young children, and the elderly are at particular risk (Pope 2000). Particulate matter emissions from oil operations come from diesel vehicles used for transport, dust entering the air during well-pad construction, and diesel engines used to power machinery at oil facilities. Particulate pollution is also emitted during flaring operations, which is common in refineries, but also occurs at wells. When a well is first drilled, it is tested to determine the characteristics of the underground reservoir, such as pressure, flow, and composition of the oil in the well. The flaring can last for a few days or a few weeks, depending on when the flow of oil from the well and the pressure are stabilized. Flaring creates significant air pollution and increased exposure to particulates.

The hazardous air pollutants (HAP) emitted from oil fields include benzene, toluene, ethylbenzene, xylenes (collectively referred to as BTEX), and many others. Benzene is a known human carcinogen and has been linked to leukemia, lymphomas, and other hematological (blood) cancers. Maternal benzene exposure has been associated with decreases in birth weight and head circumference (Slama et al. 2009). A recent scientific review of benzene's health effects noted, "There is probably no safe level of exposure to benzene, and all exposures constitute some risk in a linear, if not supralinear, and additive fashion." (Smith 2010).

The benzene content of gasoline is strictly regulated by the Environmental Protection Agency (EPA), which in 2011 lowered the allowable concentration in gasoline from 1% to 0.62% in an effort to reduce cancer risk. The State of California requires under Proposition 65 that oil companies warn the public regarding hazardous chemicals, including benzene and toluene. While the South Coast Air Quality Management District now monitors for benzene in some instances (e.g., in Wilmington, largely due to organizing by environmental justice groups), there is little or no benzene monitoring in other Los Angeles oil fields. As a result, there is insufficient data on benzene emissions in communities where oil wells are located.

Air pollution has been connected to adverse birth outcomes such as infant mortality, birth defects, and low birth-weight[9] (Morello-Frosch et al. 2010; Ponce et al. 2005; Proietti et al. 2013; Ritz 2002). While the dynamics leading to adverse birth outcomes are complex, including a combination of maternal health and social factors such as poverty, genetics, and environment, there are growing concerns over exposure for pregnant women and fetuses in drilling-intensive regions. For example, a study near gas-drilling operations found that density and proximity of wells were associated with congenital heart defects (McKenzie et al. 2014). A review of the scientific literature found that many chemicals used in unconventional oil and gas operations have been measured in air and water near operations, linked with adverse reproductive and developmental health outcomes in laboratory studies, and associated with adverse human reproductive health outcomes in epidemiological studies (Webb et al. 2014).

Demographic Characteristics in Selected Areas Hosting Oil Production Facilities

LOCATION	PEOPLE OF COLOR	200% POVERTY	RENTERS	LINGUISTICALLY ISOLATED	LESS THAN HIGH SCHOOL EDUCATION
L.A. County	72.6%	37.3%	46.9%	12.4%	27.0%
L.A. City	72.9%	44.5%	56.2%	18.7%	30.8%
Within 1,500 ft. of an active L.A. City well	74.4%	42.3%	55.7%	18.5%	30.3%
University Park: Allenco	87.0%	72.6%	90.6%	50.0%	42.5%
Historic West Adams: Jefferson	83.4%	73.5%	70.9%	27.0%	48.5%
Historic West Adams: Murphy	89.7%	60.2%	73.4%	21.8%	35.5%
Wilmington: Warren E&P	99.7%	53.6%	76.6%	42.4%	54.3%
Baldwin Hills: Inglewood Oil Field	78.8%	45.2%	34.9%	2.0%	30.1%

Analysis by authors using the 2010 US Census.

Sensitive Land Uses in Selected Areas Hosting Oil Production Facilities

LOCATION	NUMBER OF SCHOOLS	CHILDCARE FACILITIES	SCHOOLS PER 10,000 PEOPLE	CHILDCARE PER 10,000 PEOPLE	CHILDCARE PER SQ. MILE
L.A. County	3,036	3,903	3.09	3.98	1.6
L.A. City	1,087	1,385	2.88	3.67	2.9
Within 1,500 ft. of an active L.A. City well	40	29	3.25	2.35	1.5
University Park: Allenco	5	2	7.83	3.13	8.0
Historic West Adams: Jefferson	1	2	1.29	2.59	8.0
Historic West Adams: Murphy	3	1	5.44	1.81	4.0
Wilmington: Warren E&P	0	1	0.00	2.35	2.4
Baldwin Hills: Inglewood Oil Field	2	7	3.64	2.35	4.4

Analysis by authors using the 2010 US Census.

CA Department of Education CBEDS, 2013, State Licensing Division, 2013 Dun and Bradstreet and Southern CA Association of Governments, 2008.

[9] Low birth-weight is defined as, "the percent of live births weighing less than 2,500 grams (5.5 pounds)."

The juxtaposition of oil facilities with residential land is both a historical accident and zoning failure, but it is not safe, prudent, or reasonable.

South Los Angeles, the location of several new and restimulated wells, and home to communities profiled in this report, already has a higher rate of low birth-weight births (8.1%) than seen across the rest of Los Angeles County (7.1%) and the State of California (6.8%) (Los Angeles County Department of Public Health 2013)[10], with some zip codes (e.g., 90007 and 90008) facing low birth-weight rates as high as 11% and 12% in babies born in 2012. Existing high rates of low birth-weight indicate chronic underlying health vulnerability. New and newly opened oil wells present an environmental hazard that exists on top of this underlying vulnerability. Babies born with low birth-weight are at an increased risk for death in the first year and for serious long-term health problems. Local variations in air pollution can impact these outcomes, making them more severe near more concentrated pollution sources (Wilhelm and Ritz 2005). Increases in air pollution from increased oil production in already vulnerable areas have the potential to increase the incidence of adverse birth outcomes.

Oil Extraction and Environmental Justice

It has been well documented that a variety of environmental hazards and public health threats throughout the greater Los Angeles area are concentrated in neighborhoods with high rates of poverty, unemployment, linguistic isolation, and a higher residential proportion of people of color (Sadd et al. 1999; Morello-Frosch et al. 2002; Hricko 2008). Similar patterns have been documented in other metropolitan areas, and on a national scale, all are referred to under the umbrella of "environmental justice." The presence of environmental justice neighborhoods in the Los Angeles area is clear and widely accepted. Governmental and regulatory agencies recognize this problem, and have developed programs and fashioned procedures for their study and solution.

We find that several of the neighborhoods in Los Angeles now experiencing expanded oil drilling and development exhibit strong patterns of disproportionate exposure to hazards and risk, as well as high socioeconomic vulnerability. Indeed, they are classic "environmental justice" neighborhoods with high proportions of people of color, and many health, economic, and social challenges (American Lung Association 2014; Morello-Frosch et al. 2002; Morello-Frosch, Pastor, and Sadd 2001; Sadd et al. 2011). Some neighborhoods hosting oil production facilities have much higher proportions of people of color, low-income residents who are often renters, adults over age 25 with low educational attainment, and the linguistically isolated, defined by the U.S. Census as households where no one over age 14 speaks English well. These relationships are particularly striking in the Wilmington, Harbor Gateway, and Mid-City neighborhoods of Los Angeles.

Another way to investigate the non-occupational impacts of oil production is by evaluating the proximity of these facilities to populations in various communities. The California Air Resources Board (CARB) issued recommendations to local government for creating buffers for sensitive land uses such as schools, hospitals, urban parks and playgrounds, and daycare centers, to separate them from sources of air toxics (California Air Resources Board 2005). A recent report written by the City of Los Angeles

Population Density and Percent Children and Elderly in Selected Areas Hosting Oil Production Facilities

LOCATION	POPULATION (2010)	LAND AREA (mi^2)	POP DENSITY (10^3 persons $/mi^2$)	POPULATION AGE < 5	POPULATION AGE > 64
L.A. County	9,818,605	2,477	3,964	5.4%	13.1%
L.A. City	3,775,046	470	8,032	7.6%	8.5%
Within 1,500 ft. of an active L.A. City well	123,147	19.57	6,293	4.4%	11.2%
University Park: Allenco	6,382	0.25	25,528	4.2%	5.9%
Historic West Adams: Jefferson	7,729	0.25	30,916	7.1%	6.9%
Historic West Adams: Murphy	5,516	0.25	22,064	5.9%	13.6%
Wilmington: Warren E&P	4,258	0.42	10,138	10.0%	7.3%
Baldwin Hills: Inglewood Oil Field	5,501	1.59	3,462	4.0%	20.7%

Analysis by authors using the 2010 US Census and Southern California Association of Governments, 2008.

[10] Data comprises the Southwest Health District within Service Planning Area 6 of the Los Angeles Public Health Department.

MAP 2: Proximity of New and Active Oil Wells to Residential Areas in South Los Angeles

Land use within 1,500 feet of new and active wells in in South Los Angeles (Data from Southern California Association of Governments 2008).

Planning Department recommends that the City develop new land use and zoning regulations for oil and gas operations, citing a similar ordinance passed by the City of Dallas in 2013. CARB guidelines, for example, recommend 1,000 feet from most land uses characterized by high levels of air toxics emissions. Locally, the South Coast Air Quality Management District Rule 1148.2[11], passed in 2013, requires notification and reporting of oil drilling activities within a 1,500-foot zone.

Of the 1,071 active oil wells in the City of Los Angeles, 759 (over 70%) are located within a 1,500-foot buffer distance from residences and other sensitive land uses. In some of these areas, people and sensitive populations are also concentrated at levels higher than regional averages. A comparison of socioeconomic indicators for residents living within 1,500 feet of active wells demonstrates that the local impact of oil production is significant in some neighborhoods hosting active oil production wells. For example, population density is several times higher in these neighborhoods. There is a similar relationship with a higher proportion of "sensitive land uses" close to active oil wells—these land uses (e.g., schools and childcare facilities) have been defined by CARB as deserving special attention because biologically sensitive populations spend extended time in these facilities (CARB 2005). Similarly, the proportion of people who are biologically sensitive to air pollution and cancer-causing chemicals—the very young and the elderly—is higher in some of these areas when compared to regional averages.

Another way to evaluate oil production in terms of environmental justice—the extent to which these facilities are located in already overburdened neighborhoods—is by use of CalEnviroScreen 2.0[12], the screening methodology developed by CalEPA to help state regulatory agencies identify California communities that are disproportionately burdened by multiple sources of pollution[13]. Many oilfields inside the city boundaries are located in areas identified by CalEnviroScreen 2.0 as among the most overburdened in the entire state.

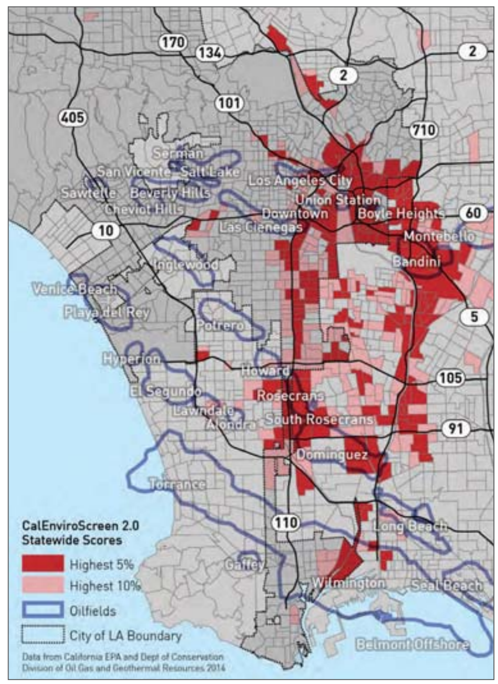
Land use in the vicinity of active oil production varies in different parts of Los Angeles, exposing communities to real and potential impacts of oil production. Some oilfields in the Los Angeles region are surrounded by open space or industrial, commercial, or vacant land. However, in some neighborhoods, this highly industrial and potentially hazardous activity takes place adjacent to residences, schools, parks, and public facilities.

[11] http://www.aqmd.gov/docs/default-source/rule-book/reg-xi/rule-1148-2.pdf?sfvrsn=4

[12] A screening method developed by CalEPA Office of Environmental Health Hazard Assessment that is used by state government agencies to identify communities that are disproportionately burdened by multiple sources of pollution. CalEnviroScreen uses science-based techniques to evaluate multiple pollution sources and the resident population's vulnerability to that pollution's adverse effects, calculating a score for each census tract in the state. A final score, expressed as a percentile, is calculated from the ranked values for all tracts statewide. The highlighted tracts in Map 3 have percentile scores that are in the top 10% of all tracts statewide for all indicators of pollution burden and population vulnerability used by the CalEnviroScreen tool.

[13] http://oehha.ca.gov/ej/eces2.html

MAP 3: Proximity of Environmental Justice Communities to Oil Fields in the Los Angeles Region



Shown are census tracts with CalEnviroScreen 2.0 scores in the top 5% and 10% statewide and their proximity to oil fields in the region. CalEnviroScreen 2.0 is the State of California's official tool for identifying communities that are disproportionately burdened by multiple sources of pollution and high levels of social vulnerability. Note that five of the six oil fields wholly within the City of Los Angeles' boundaries affect communities within the top 5% and top 10%. These oil fields are Boyle Heights, Las Cienegas, Los Angeles City, Los Angeles Downtown and Union Station.

Almost one quarter (253/1,059) of active wells in the city are located on residentially zoned land (mostly multifamily and high density). Map 2 shows the juxtaposition of residential land with active oil production wells in the South Los Angeles area. These and other communities are profiled in the next section of this report, "Families on the Frontlines."

The Problem of Proximity

Why do we consider oil development in close proximity to people a problem? These activities are not compatible with densely populated neighborhoods with sensitive populations and pose a threat to human health and the environment. Oil is extracted using technologies such as acidizing that use harsh chemicals such as hydrochloric acid, as well as a mix of chemicals that are identified carcinogens, reproductive toxins, and endocrine disruptors.

Oil drilling and production adds to the burden of air pollution in these neighborhoods. The city has battled air pollution for decades and still faces the worst levels of ozone in the country, and the chemicals and particulates in air pollution have been linked to a variety of health problems such as exacerbated asthma, adverse birth outcomes, and premature death. Environmental justice neighborhoods in Los Angeles face higher levels of air pollution and worse health outcomes than residents of the region overall, and these residents tend to be more vulnerable to these environmental threats.

Many of the neighborhoods that host oil drilling and production have already been identified by cumulative impacts screening because of their high exposure to environmental hazards and pollution, and the high vulnerability of their residents. These communities have high proportions of people of color, high poverty and language barriers, low home ownership and education, and concentrations of schools and childcare. Oil development is a highly industrial activity which generates considerable pollution and risk to those living, playing and going to school just over the fence line. The juxtaposition of oil facilities with residential land is both a historical accident and zoning failure, but it is not safe, prudent, or reasonable.

FAMILIES ON THE FRONTLINES: WHEN OIL IS YOUR NEIGHBOR

Heavy equipment at the Jefferson Drill Site is right next to homes in the Historic West Adams neighborhood.

Los Angeles neighborhoods are defined in many ways—by geography, density, history, and more. The neighborhoods described in the following pages are defined by their proximity to a particular oil drilling facility.

In University Park, near the University of Southern California (USC), Monic Uriarte describes how nauseating fumes clued the community in to the fact that the Allenco drill site was behind the high walls near their homes. In Historic West Adams, west of USC, Richard Parks and other residents were alarmed to learn that the Jefferson drill site, a local eyesore with its concrete wall and trashy parkway, was pumping carcinogenic chemicals under their homes.

Historic West Adams, with homes dating from the turn of the 20th century, is also home to what Don Martin, Joanne Kim, and other residents know as the Murphy drill site. It opened in the 1960s, but in recent years new extraction techniques have exposed the community to new hazards. In Wilmington, near the ports of Los Angeles and Long Beach, Ashley Hernandez is deeply worried about expansion of the Warren E&P drill site because air pollutants from the site have already hurt her family's health.

Baldwin Hills is one of three neighborhoods bordering the Inglewood Oil Field. Residents there, including Charles Zacharie, monitor health and environmental impacts of drilling on Baldwin Hills, Inglewood, and Culver City.

Together, these stories of concerned and active neighbors paint vivid pictures of Angelenos hit hard by the day-to-day consequences of expanded urban oil development.

When Regulators Fail
University Park: Allenco Drill Site

Barbara Osborn, Ph.D., *Annenberg School of Communications and Journalism, University of Southern California*

Monic Uriarte placed the first of dozens of calls to the South Coast Air Quality Management District (SCAQMD)'s "odor complaint" line in late 2010. She and her family smelled a strong, unpleasant odor in the air on the long weekend of the Martin Luther King holiday. They had smelled odors before, but not like this. In the past, odors had passed in minutes. Monic began to feel nauseous. Her 10-year-old daughter Nalleli's nose began bleeding. That night, Monic turned on an air purifier in her bedroom and she, her four kids, and her mother squeezed into one room so they could sleep.

Monic Uriarte and daughter Nalleli suffered for years from unexplained health problems.

The stench persisted. Monic and her neighbors on West 23rd Street, near the University of Southern California, located the odor complaints number at the SCAQMD and began calling. That was when she realized that the narrow strip of grass across from her home, where she'd taken her kids for picnics, was the landscaped exterior of the Allenco Energy oil drilling facility. It would be years before she would learn that Allenco had recently increased its production at the site 400% (Sahagun, September 21, 2013).

After several days the smell subsided, but Nalleli began complaining of intense stomachaches and headaches. She developed heart palpitations and severe body spasms. For a time, she was not able to walk. Monic took Nalleli to a cardiologist, a gastroenterologist, and a neurologist. Nalleli had an MRI and wore a heart monitor for weeks, but doctors couldn't explain the little girl's illness.

Meanwhile, the overpowering odors came and went. Monic's neighbors called the SCAQMD regularly. They learned to provide exactly the information that SCAQMD operators required to dispatch an inspector: Their name. Their location. The location and description of the smell. They learned that the SCAQMD has to receive six calls from people in six different households before it can determine whether the odor issue is a public nuisance. It took several hours, sometimes days, for the SCAQMD to respond. Monic would call with a complaint on a Sunday, leave a message, and get a call back on Tuesday.

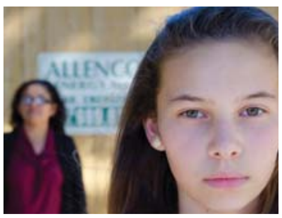
In the best of circumstances, neighbors would reach a live SCAQMD operator and a sufficient number of calls were made within the hour to warrant dispatching an inspector. Three or more hours later, an inspector would arrive, put his or her nose in the air and sniff. If the inspector didn't smell anything, no complaint could be filed.

For two years, community residents called the SCAQMD with hundreds of complaints and nothing changed. They still didn't understand what was making so many of them sick. The community tried to conduct its own air quality monitoring but without knowing the chemicals that were being emitted from the Allenco facility, they couldn't tell the lab what to look for. By attending a toxicologist's lecture, Monic finally identified an explanation for her daughter's illness. Nalleli's symptoms were all consistent with exposure to hydrogen sulfide (H_2S), a flammable, colorless gas that occurs naturally in petroleum and natural gas. Exposure triggers respiratory irritation, headache, dizziness, and vomiting (Sahagun, September 21, 2013).

By chance, Monic and Nalleli finally got a close look at what lay behind the high walls surrounding the Allenco facility. They'd enrolled in a local photography workshop and their assignment was to take photographs of their community. As they walked their neighborhood taking pictures, they discovered the gates of the Allenco facility open. They asked a worker if he could show them around and the man took them to see the wells. He explained he had to open release valves every 10 or 15 minutes or they would explode. Pipes near the wells read "Danger: H_2S poisonous gas" (Sahagun, September 21, 2013). Monic recalls that as they entered the underground area near the wells, she felt as if "her head was going to explode," but the worker wore no protective gear and didn't suggest to Monic or her daughter that they needed any.

Neighbors began sharing information and struggling to get regulatory agencies to be more responsive. They formed a neighborhood group called "People Not Pozos." ("Pozos" is a Spanish word meaning "well.") Members of the group approached the *L.A. Times*, and after a *Times* article appeared

They learned that the SCAQMD has to receive six calls from people in six different households before it can determine whether the odor issue is a public nuisance.



Nalleli and her neighbors do not want the Allenco facility to reopen.

in September 2013, Senator Barbara Boxer's office got involved. Suddenly, regulatory agencies became responsive. The SCAQMD began returning Monic's calls within two hours instead of two days. Investigators from the United States Environmental Protection Agency (EPA) came to the neighborhood and were sickened on the site (Sahagun, November 8, 2013).

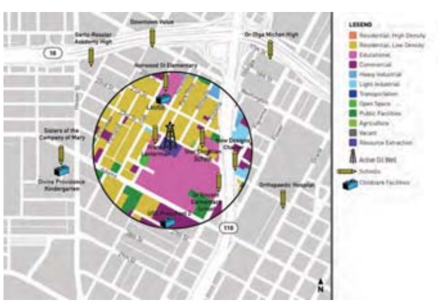
Late in November 2013, Allenco agreed to temporarily close the facility. For the first time in years, residents were able to enjoy Thanksgiving with their windows open. Their symptoms cleared. Monic had no headaches. Nalleli's nosebleeds and stomachaches disappeared.

Two months later, the EPA cited Allenco for jeopardizing the health of the community (Sahagun, January 15, 2014). The L.A. City Attorney's office filed suit, citing SCAQMD monitoring that now revealed elevated concentrations of hydrocarbons and other chemicals like methane, ethane, benzene, and propane, plus hydrogen sulfide and other sulfur compounds. Allenco agreed to make $700,000 in upgrades to comply with the federal Clean Air and Clean Water Acts (Duroni 2014). In July 2014, the U.S. EPA fined Allenco $99,000 for failure to comply with requirements around hazardous substance reporting, while the suit by the L.A. City Attorney alleged that the company was "willfully disregarding violation notices" from regulatory agencies (Sahagun, July 30, 2014).

But after years of fighting to get regulators to respond, Monic and her neighbors don't want the facility reopened. She has lost confidence that the regulatory agencies which were supposed to protect her family have made the changes in their own procedures to ensure community health in the future. Monic has lost her sense of smell, a symptom consistent with hydrogen sulfide exposure, and without it, she can't be sure she could detect toxic chemicals if she were exposed to them.

Nancy Ibrahim, executive director of the Esperanza Community Housing Corporation, which owns two buildings on 23rd Street near the Allenco facility and whose tenants were affected by the fumes, says, "Since 2011, residents logged in hundreds of phone complaints to SCAQMD and nothing changed. This is a residential community with nine educational institutions and early childcare facilities. Residents were left entirely unprotected by the regulations that are supposed to protect them. SCAQMD's current procedures are not adequate to safeguard the health of this or any other neighborhood."

MAP 4: Land use within 1,500 Feet of the Allenco Energy Oil Facility in University Park



(Data from Southern California Association of Governments 2008).

"How are these chemicals being used?" Historic West Adams: Jefferson Drill Site

Barbara Osborn, Ph.D., *Annenberg School of Communications and Journalism, University of Southern California*

"At first, all we wanted were good neighbor kind of things," explained Richard Parks, the father of three young children who lives in a neighborhood off Jefferson Boulevard, just west of the University of Southern California in the City of Los Angeles.

Parks and his neighbors were unhappy that the entire block on Jefferson Boulevard between Van Buren and Budlong Avenues was an eyesore, littered with trash and graffiti and surrounded by a 10-foot concrete wall. Mothers picking up their children at local elementary schools were forced to push strollers into traffic because large trucks blocked the sidewalks, and the weight of those trucks was leaving sidewalks broken and unsafe.

In the beginning, neither Parks, the director of the Center for Social Innovation at USC's Sol Price School of Public Policy, nor his neighbors had any idea they were about to stumble on a danger far more threatening than graffiti and unsafe sidewalks. As Parks and his neighbors began to press for cosmetic changes, they learned that the site was owned by Freeport-McMoRan, a natural resources company. They also learned that Freeport-McMoRan planned to dramatically expand production. The company wanted permission to drill three new wells, in addition to the 29 already on the site, and the right to drill 24/7 for somewhere between two months and two years!

Richard Parks and his family are residents of Historic West Adams near Jefferson Boulevard and Budlong Avenue which hosts one of Freeport-McMoRan's oil drilling sites.

Then one Friday afternoon, almost by chance, Parks noticed an email about a public hearing involving the Freeport-McMoRan site to be held the following Tuesday. He cancelled his appointments for the afternoon and hustled to Los Angeles City Hall to find out what the hearing was about. To his astonishment, he discovered that Freeport-McMoRan was asking for permission to work around the clock to drill the three new wells on the site. If he hadn't seen the email and run downtown, none of the families, nor the USC students who live in the neighborhood, would have known about it.

He quickly notified neighbors. Several residents attended the hearing, as did a small army of Freeport-McMoRan representatives. When the Department of City Planning asked for proof that the company had provided adequate public notice, Freeport couldn't produce it. In fact, Parks learned, the company had repeatedly asked the City to waive the public hearing requirement. Faced with the company's noncompliance and the community's concern, the City refused to grant the permit.

Shortly after the hearing, Freeport-McMoRan contacted Parks to set up a meeting. Parks suggested the company meet with key community stakeholders, including representatives from Congresswoman Karen Bass and Councilman Bernard Parks' offices, but Freeport-McMoRan insisted on meeting with him alone. Parks agreed, and at that meeting, he shared the community's concerns. The company executive scoffed, "Look, this isn't exactly Laguna Niguel," a reference to the beachside city where incomes are four times greater than the median income in Parks' USC-adjacent neighborhood.

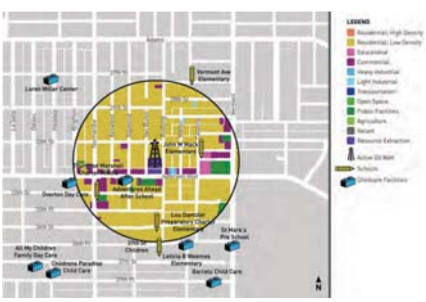
As Parks and other community residents shared their experiences with each other, their alarm grew. Neighbors recalled the day when their homes and cars were covered by a spray of oil. Something—to this day residents don't believe they've received a full explanation—occurred on the site, and an adjacent home and cars on the street were sprayed with oil. Freeport-McMoRan paid to repaint the affected home and clean the cars. "The company called it a 'misting,'" Parks says, "like it was a fine French perfume."

That summer, Parks learned that nearly 91,000 pounds of toxic chemicals including corrosive acids had been pumped under residents' homes in July 2014.

Residents walking children to school worry about hazards from oil wells.

In May of 2014, Parks was walking past the Freeport-McMoRan site and a truck pulled up with a long list of toxic chemicals posted on the outside. Thanks to the South Coast Air Quality Management District's regulation 1148.2, passed in 2013, Parks already knew that Freeport-McMoRan had injected more than 42,000 pounds of toxic chemicals (including corrosive acids and carcinogenic material) into the ground in the previous 12 months (South Coast Air Quality Management District 2013). But the truck Parks saw that day listed additional toxic chemicals that had not been included in the company's report to the SCAQMD. Parks tried to talk to the driver and take a few photographs, but the driver quickly drove away. That summer, Parks learned that nearly 91,000 pounds of toxic chemicals including corrosive acids had been pumped under residents' homes in July 2014. (South Coast Air Quality Management District 2013). There was no doubt that unconventional oil drilling techniques were being used at the site.

MAP 5: Land use within 1,500 feet of Freeport-McMoRan's Oil Facility located at the intersection of Jefferson and Budlong in Historic West Adams



(Data from Southern California Association of Governments 2008).

Neighbors have begun to wonder whether a local resident's cancer or the fact that mature trees on an adjacent lot are suddenly dying could be linked to soil contamination on the site. For now, the community has no way to answer those questions. The total disclosed chemicals used on the site between July 2013 to August 2014 has grown to 133,766 pounds. "Even my second-grader understands that injecting hundreds of thousands of pounds of acid in the ground isn't a good thing," Parks said.

Unexpectedly, early in 2015, Freeport-McMoRan decided to withdraw their application to drill an additional three wells on the site. None of the residents know why. Parks credits the drop in global oil prices and the extraordinary community response. But, he added, "the application withdrawal doesn't mean we can return to the status quo. The community documented numerous and serious violations of conditions that threaten residents' health and safety. The city now has a duty to hold Freeport-McMoRan Oil & Gas (FMOG) accountable for these violations and to strengthen conditions to better protect residents."

According to Parks, "At its best, Los Angeles is trying and failing to address our 21st century understanding of toxic chemicals' multi-generational health impacts with a planning code from the last century that was deeply influenced by the oil industry. At its worst, the City has allowed FMOG to sell vacant buffer properties to residential developers. Instead of buffer properties serving residents, the Planning Department has turned residents into buffers. The conflict between the company and the community demonstrates the need to forge a new and stronger regulatory framework. In the face of flagrant violations, the City needs a clear path to revocation of conditional land use permits for residential oil extraction."

Fumes, Fears, and Frustration
Historic West Adams: Murphy Drill Site

Barbara Osborn, Ph.D., *Annenberg School of Communications and Journalism, University of Southern California*

One neighbor after another started to wonder what on earth was going on. First, an unsightly 20-foot-tall beige sound wall went up across the entire north side of the block around an oil facility known to locals as the "Murphy" drill site. Everyone who lived in the neighborhood of historic homes knew you couldn't do that without a permit from the Historic Preservation Committee.

Don Martin and his granddaughter, Kiarri, live next door to the Murphy drill site.

Other neighbors complained about smells. Residents began sharing complaints about odors coming from the Murphy site and began to circulate information about what to do if you smelled something. That's how Donna Ann Ward, who lives a few blocks from the Murphy site, knew to call the South Coast Air Quality Management District (SCAQMD) when she stepped into her backyard the morning of January 7, 2014 and thought she smelled something "sulfury" in the air.

She called the SCAQMD and four hours later, an inspector discovered a leak of "unodorized" natural gas at 40 times the allowable limit and issued a citation to Freeport-McMoRan Oil & Gas, the company that runs the site, which currently includes 22 active production wells and seven active injection wells. Donna's phone conversation left her asking more questions: Is unodorized a technical term? It sounds like something that has had its odor removed. If it was unodorized, where was the "sulfury" odor coming from?

The incident made Donna Ann aware that the Murphy site might pose a fire hazard. According to the 2010 U.S. Census, 14,870 people live within a half-mile radius of the wells. Given that the neighborhood is home to a special needs high school, a 900-student elementary school, a hospice facility, and a senior housing complex, she wondered what kind of plans had been made in the event of an emergency.

All around the neighborhood, residents have similar stories. Don Martin lives next to the Murphy drill site, in the St. Andrews Gardens Apartments on West Adams Boulevard. The Section 8 complex includes 192 apartments with a basketball court and a kids' playground at the heart of the complex. The Murphy drill site operates 24 hours a day.

Like many of his neighbors, Don keeps his windows closed most of the time, running up expensive air-conditioning bills, but it's the best strategy for keeping out the noise, fumes, and ash that often blow across the apartment complex.

Don is also unnerved by the sign on the Murphy drill site entry gates: "Warning: This area contains chemicals known to the State of California to cause cancer or birth defects or other reproductive harm." His 11-year-old granddaughter Kiarri developed Hodgkin's lymphoma three years ago, and while he can't prove it, he fears her illness is related to the Murphy site. He doesn't believe regulators are really tracking what's happening and he doesn't trust the information Freeport-McMoRan is providing to the community. "They [Freeport-McMoRan] keep us out," he says, "but they can't keep the chemicals in."

Donna Ann Ward feels similar fear and frustration. While Freeport-McMoRan says it has an Integrated Contingency Plan and Emergency Response Action Plan on file with the appropriate regulatory agencies, local fire station chiefs told her they did not have an emergency response plan, or even a map of the Murphy facility in the event of an explosion.

Other residents spent long hours reviewing City of Los Angeles Planning Department documents, trying to determine whether drilling at the Murphy site had been started without necessary permits, or was inappropriately approved.

Community concern culminated in January 2014, when 300 residents turned up at a meeting at Holman United Methodist Church, just a few blocks from the Murphy site. Los Angeles City Council President Herb

Local fire station chiefs told her they did not have an emergency response plan, or even a map of the Murphy drill facility in the event of an explosion.

Wesson, California State Senator Holly Mitchell, and United States Congresswoman Karen Bass were present. During the meeting, Wesson announced that he would instruct the Los Angeles Department of Building and Safety to stop the construction of the new wells. In addition, Freeport-McMoRan must now submit new plans and participate in public hearings to proceed with its expansion plans and the construction of new wells.

After the meeting, Wesson persuaded the Los Angeles City Council to pass a motion asking the City Attorney to draft an ordinance for a citywide moratorium on extreme and unconventional oil extraction until it was studied and deemed safe.

Residents are grateful for Wesson's efforts, but they continue to be deeply concerned about lack of transparency and inadequate regulation. Joanne Kim, who lives in the neighborhood with her husband and two young children, notes that at least eight different government agencies regulate the oil industry. "There are too many cooks in the kitchen, which makes it difficult for us to get a full picture of what's going on. Almost every agency we contacted directed us to another agency for answers." The type of drilling that's being done and the chemicals being used are qualitatively different than they were when the Murphy site first opened in the 1960s, she continues. "The way in which government regulates this unconventional activity in 2014 has also got to be qualitatively different."

Joanne Kim and her daughter live near the Murphy drill site.

MAP 6: Land use within 1,500 feet of Freeport-McMoRan's Murphy Oil Facility in the Historic West Adams neighborhood

(Data from Southern California Association of Governments 2008).

"No false solutions!" Wilmington: Warren E&P Drill Site

Barbara Osborn, Ph.D., *Annenberg School of Communications and Journalism, University of Southern California*

When Ashley Hernandez sits on her front stoop with her dog Lucy, she smells oil in the air on the lovely tree-lined street in the Wilmington neighborhood in the City of L.A. where she and her family live. It doesn't matter whether it's day or night, the smell is always there. Half a block from her home, right next to the John Mendez baseball park, an enormous oil rig towers over Opp Street. It's open 24 hours a day, so the noise and the odors are a constant nuisance for the neighborhood.

Ashley Hernandez suffered health problems from oil drilling in her Wilmington neighborhood.

According to a recent analysis by California environmental agencies, parts of Wilmington (a neighborhood near the Los Angeles and Long Beach Ports), rank among the top 5% of communities with the highest pollution exposure and social vulnerability in the state (Office of Environmental Health Hazard Assessment CalEnviroScreen2.0, 2014). The most recent study from the SCAQMD (MATES IV 2014) reports significant reductions in cancer risk over the last decade. However, the estimated cancer risk in some parts of Wilmington is the highest in Southern California, exceeding 1,000 additional cancers per million residents, three orders of magnitude higher than the National Clean Air Act goal of one in one million. Moreover, new research from the State's Office of Environmental Health Hazard (OEHHA) has determined that previous methods for estimating cancer risk were insufficient, and cancer risk estimates are higher by nearly three times than previously understood.

Ashley is familiar with all these statistics, but they don't tell her anything she doesn't already know firsthand. She remembers when she and her family moved to Wilmington from North Hollywood, nearly 10 years ago, to be closer to her dad's new job at the Ports of L.A. and Long Beach. Her mother developed respiratory problems. Ashley developed a pollution-related eye irritation her senior year in high school that was so severe her attendance and grades suffered. Her doctor attributed both mother and daughter's health problems to particulates in the air in and around their home. Ashley's sister used to jog when she lived in Santa Barbara. Now she lives in Wilmington and her lungs simply won't tolerate it.

Her family's health is the prime reason Ashley is so concerned about the expansion at the Warren E&P site near her home, as well as oil extraction technologies being used elsewhere in the vicinity of the ports. Thanks to a new regulatory safeguard (SCAQMD Rule 1148.2), companies are now required to report plans to acidize, gravel pack, and frack, as well as to report the chemicals they use as part of their oil extraction practices. Ashley knows that oil companies in Wilmington are using known carcinogens and engaging in gravel packing and acidization. A recent report issued by the Center for Biological Diversity and Physicians for Social Responsibility, which examined the first year of data provided by the oil companies, revealed that more than 45 million pounds of dangerous chemicals had been used in Los Angeles and Orange counties. More than half of these "chemical-intensive events" occurred in oil wells within 1,500 feet of a home, school, or medical facility (Center for Biological Diversity, Physicians for Social Responsibility – Los Angeles, Communities for a Better Environment, and the Center on Race, Poverty and the Environment 2014).

Data provided by the oil companies revealed that more than 45 million pounds of dangerous chemicals had been used in L.A. and Orange counties.

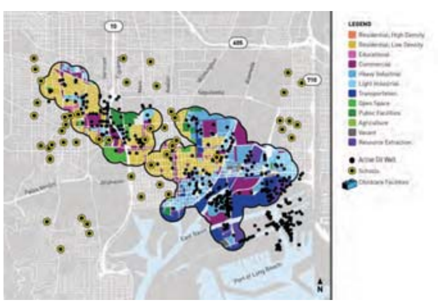
Those findings leave Ashley deeply worried. She has learned not to trust that Warren E&P will be a good neighbor or that regulatory agencies have the ability to safeguard her family or her neighbors' health.

The Hernandez family was new to Wilmington in 2006 when a local community organization, Communities for a Better Environment, documented the failure of regulatory agencies to protect the community after Warren E&P began to expand its operations at the site near the Hernandez home (Fazeli 2009). Both the City of Los Angeles and the SCAQMD failed to anticipate the health impacts on the neighborhood of increased truck traffic, dirt and dust blanketing the area, foul smells, and construction noise. The City and the SCAQMD permitted the company's day and night drilling application. Neighbors called it a "living hell" (Fazeli 2009).

Ashley doesn't have a lot of confidence in Warren E&P's transparency or integrity. Periodically, she says, representatives of Warren E&P go door-to-door offering neighbors free carwash coupons or gas gift cards. They sponsor the local Pony League that practices adjacent to the Warren E&P rig near her home. The company sponsors field trips for the local schools and built a park in the neighborhood on reclaimed land. Approximately 1,500 Wilmington residents receive royalty checks as a result of the drilling (Agostoni 2008). In Ashley's view "the company is offering false solutions that distract from the community's real health problems. A hundred dollar gift card is nice," she says, "but it won't pay for an emergency room visit."

Ashley Hernandez is now the Youth Organizer for Communities for a Better Environment in the Los Angeles area.

MAP 7: Land use within 1,500 feet of Oil Wells in Wilmington



(Data from Southern California Association of Governments 2008).

Largest Urban Oil Field in the Country Baldwin Hills: Inglewood Oil Field Drill Site

Erin Steva, MPP, *Environmental Health Policy Analyst, Community Health Councils*

Charles Zacharie of Baldwin Village is concerned about the health effects of the largest urban oil field in the country.

More than one million people live within five miles of the Inglewood Oil Field, the largest contiguous urban oil field in the country. At 1,000 acres, located near the center of sprawling Los Angeles County, it is nearly as large as the City of West Hollywood. The people are as diverse as the surrounding Baldwin Hills, Inglewood, and Culver City neighborhoods—50% African American, 17% Caucasian, 15% Hispanic and 6% Asian-Pacific Islander (Los Angeles County Department of Regional Planning 2008).

Charles Zacharie of Baldwin Village grew up next to fields watching the pumping jacks bob up and down. Now, Charles says, "I drive past the field every day going to work and have noticed diesel or industrial smells like sulfur. I look at the field around me and know where it must be coming from." He frequently visits the beautiful Kenneth Hahn State Recreation Area, which sits adjacent to the Inglewood Oil Field. When there, he's noticed diesel odors and a soapy lemongrass fragrance, which he was later told is used to cover up odors. He's unsettled by "odor suppressants," because it means there are potentially dangerous fumes being disguised.

For the surrounding park-poor South Los Angeles neighborhoods[14], Kenneth Hahn Park is an invaluable resource, giving residents a swath of open space and greenery in the midst of a sea of asphalt and concrete (Garcia, Meerkatz and Strongin 2010). But Charles, like many of his neighbors, is concerned about the health impacts of living and playing so close to 700 active oil wells (Paillet 2013). He wonders whether his neighbors' breast cancer or respiratory issues result from living near the field, and he's concerned about new extraction technologies.

In early 2006, families in the Culver Crest neighborhood were evacuated twice for noxious odors (Los Angeles County Department of Regional Planning 2008). Local resident John Kuechle remembers waking up at three in the morning to a terrible smell that made his wife nauseous. They called the police to report the odor and evacuated their home. The oil field operator Plains Exploration & Production (PXP) described the odor release as a nonhazardous, once-in-a-lifetime event; but more incidents followed. When John asked a South Coast Air Quality Management District (SCAQMD) representative why the "nonhazardous" gas made his wife feel so ill, he learned that "nonhazardous" only meant non-explosive.

Around the same time in 2006, PXP revealed plans to drill as many as 1,000 new wells over the next 20 years. Charles and others had heard of plans to turn the oil field into a large park, and were disappointed and concerned about the effect of this proposal on those plans. Community Health Councils, the City Project, neighborhood associations, and block clubs formed the Greater Baldwin Hills Alliance to represent the 50,000 households living immediately adjacent to the oil field. Months after the noxious odor incident, Los Angeles County prohibited new drilling until 2008, providing time for the development of an ordinance to more effectively regulate drilling in the field.

John Kuechle recalls an evacuation from his home due to noxious odors from the Inglewood Oil Feld.

[14] There is less than one acre of parkland per 1,000 people in Baldwin Hills compared to the nationally recommended ratio of six to 10 acres per 1,000 people. The State of California's definition of "park poor" communities is those with less than an average of three acres per 1,000.

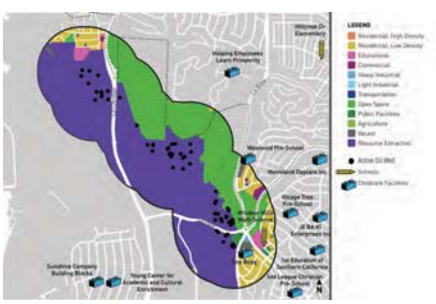
"Just because the oil company brings jobs and other benefits doesn't mean it can do it at the expense of my health and well-being," said Charles Zacharie.

Residents and neighborhood associations mobilized to ensure the environmental study and proposed zoning regulations adequately addressed the hazards and health risk to the community. Over the course of the six hearings, residents provided hours of testimony and volumes of written comments.

The Los Angeles County Board of Supervisors adopted a Community Standards District in 2008 that limited drilling to 600 new wells and required a landscaping plan, the formation of a community advisory board and multi-agency coordination council, and the installation of new air quality equipment among more than 62 pages of regulations.

In order to address shortcomings in the adopted rules, four lawsuits were filed, including one on behalf of Community Health Councils and the Natural Resources Defense Council. An agreement was reached that significantly strengthened restrictions by further reducing the number of new wells allowed, increasing air quality monitoring, setting more stringent noise limits, and requiring recurring health and environmental justice assessments. With these provisions, the Community Standards District contains many elements that are a model approach for how health-protective and community-responsive mechanisms can be required of oil operations.

MAP 8: Land use surrounding the Inglewood Oil Field located adjacent to Baldwin Hills and Culver City



(Data from Southern California Association of Governments 2008).

Charles Zacharie and other neighbors are working to limit oil field expansion.

Nevertheless, community members remain concerned and vigilant. While greatly reduced in frequency, odor complaints continue, noise levels remain problematic, and people are concerned that cracks in their foundations might be caused by the oil field. The Baldwin Hills Community Standards District is currently going through a periodic review process that is required every five years, and Greater Baldwin Hills Alliance stakeholders have recommended improvements, including better implementation of rules and health studies, and further efforts to shrink the field's size. Residents also want an emergency fund to guarantee the field is eventually cleaned up and to ensure resources are available if people's health is harmed.

John Kuechle and Charles Zacharie feel that the Community Standards District has brought needed attention to the oil field and that the operators are being watched more closely now. But the questions about the health effects of living so close to such a large, active oil field remain. "Just because the oil company brings jobs and other benefits doesn't mean it can do it at the expense of my health and well-being," said Charles.

OIL DRILLING AND THE LAW: THE BASIS FOR MUNICIPAL AUTHORITY

Freeport-McMoRan oil operations tower over the surrounding neighborhood at the Jefferson Drill Site.

Adrian Martinez, *Attorney, Earthjustice*
Yana Garcia, *Staff Attorney, Communities for a Better Environment*
Angela Johnson Meszaros, *General Counsel, Physicians for Social Responsibility – Los Angeles*

The Los Angeles Oil Code applies to all districts where the drilling of oil wells or production from wells of oil, gases, or other hydrocarbon substances is permitted (Los Angeles City Municipal Code). The Los Angeles Oil Code's primary concerns are to advance the interests of oil and gas producers, rather than promote public health and environmental protection. Importantly, these laws were last significantly updated in the 1950s, which predated many of California's landmark laws aimed at protecting residents from environmental harms, including the California Environmental Quality Act and the Porter Cologne Water Quality Control Act. Moreover, it predated passage of bedrock federal environmental laws like the Clean Air Act and Clean Water Act.

Recent evidence about the real and important impacts on residents and the environment from oil and gas development make this a good time to revisit the code to make sure it addresses the full ambit of local needs, including protecting the health and welfare of those living next to current and future oil and gas operations. In crafting these policy prescriptions, the current regulatory scheme suffers from several flaws, but most importantly the following:

- From the start, the laws and regulatory oversight processes established to address oil and gas activity were not envisioned as a way to protect residents or the environment;
- As Los Angeles became more dense, the city failed to address gaps in the existing regulatory system, and it failed to create a framework for reviewing earlier decisions to allow or place conditions on oil extraction activities;
- The systems for collecting and making publicly accessible existing information about oil extraction activities are inadequate because the most critical information is incomplete and reporting is not timely.

All three of these flaws can be addressed through revisions to the municipal code.

California courts have a long history of zealously protecting the rights of cities to protect their residents through land use controls.

Overall, the City retains ample jurisdiction to implement the policy prescriptions provided in this report. Comprehensive zoning has long been held as a valid exercise of a city's police powers (Miller v. Board). The evidence of the serious impacts this industry imposes on residents, in addition to harms to the environment that are antithetical to the City's sustainability goals, provide the basis for changing the Los Angeles Oil Code to be more responsive to the needs of residents. The City will simply need to ensure it complies with legal precedent and provides adequate safeguards to protect vested rights. While this task will take some effort and resources, the seriousness of the threats posed by oil and gas extraction merits this work.

Opponents of commonsense measures to protect public health and the environment from oil and gas development will likely raise two legal claims to seek to derail these efforts. First, they may argue that these laws are preempted by state laws. Second, they may argue that any restrictions amount to a taking and could infringe on vested rights. Both of these issues lack merit.

On the preemption issue, California courts have long upheld reasonable local zoning regulations even in the context of restrictions on oil and gas (Beverly Oil Company). In the Beverly Oil Company case, California's Supreme Court determined "[i]t must be deemed to be well settled that the enactment of an ordinance which limits the owner's property interest in oil bearing lands located within the city is not of itself an unreasonable means of accomplishing a legitimate objective within the police power of the city" (Beverly Oil Company, 558). The City's action at issue in the Beverly Oil Company case allowed for continued oil operations at a site in the city but "expressly provide[d] that no new well for the production of hydrocarbon substances, which is a nonconforming use, shall be drilled nor shall existing wells be deepened" (Beverly Oil Company, 555). The Court upheld the City's action restricting operations by noting "[i]t has not been denied the right to extract the mineral wealth underlying its property, which denial has been upheld in other cases" (Beverly Oil Company, 559). As the California Supreme Court has clearly stated, cities retain authority to adopt a wide range of policy prescriptions to address the harms of oil and gas development.

Oil industry lobbyists may also argue that existing California law, including amendments through Senate Bill 4, preempts any activity by the City. Importantly, Senate Bill 4 did not expressly preempt local actions, and there is no other evidence in California law that the State intended to preempt the rights of local jurisdictions to protect their residents through reasonable land use restrictions. The City will need to use the ample evidence contained in this report and other resources to provide the rationale for action, but California courts have a long history of zealously protecting the rights of cities to protect their residents through land use controls.

On the takings issue, the Fifth Amendment to the United States Constitution provides that "private property [shall not] be taken for public use, without just compensation" (U.S. Const., amend. V). The California Constitution contains a similar provision: "Private property may be taken or damaged for a public use and only when just compensation, ascertained by a jury unless waived, has first been paid to . . . the owner." (Cal. Const., art. I, sec. 19) Despite the fervor in which oil and gas proponents argue takings claims are a serious threat to a city's effort to enact zoning regulations, law professors from Stanford University, University of California Irvine, University of California at Berkeley, and University of San Diego School of Law articulated the uphill battle that a takings challenge would have in succeeding in a local control effort that took place in Santa Barbara County (Sivas 2014). Specifically, they articulated that a "facial" challenge to a local ordinance restricting certain types of oil and gas development would face an uphill battle in court. In addition, the law professors articulated the rigorous proof an individual property owner would need to provide in any "as applied" challenge against a city. This letter articulates clearly that a local entity like the City of Los Angeles can design a program that carefully navigates the issues related to takings and vested rights.

Proponents of unfettered oil and gas drilling in Los Angeles will claim legal issues impede any commonsense restrictions aimed at protecting residents and the environment from the harms associated with oil and gas development. These lobbyists and lawyers are wrong. The traditional role of a municipality's land use authority is to protect residents from harm. To date, the City of Los Angeles has built its laws based upon a paradigm that sought to maximize oil extraction—placing the interests of the oil industry over those of hardworking women and men, schoolchildren, and the elderly. To protect human health and the environment and to position itself at the forefront of a 21st-century approach to energy production and use, the City must shift to a paradigm that places citizens' health and welfare first. Los Angeles must be careful to craft commonsense protections based on evidence, but that hurdle is perfectly manageable.

TOWARD A HEALTHY AND SUSTAINABLE LOS ANGELES

A panoramic view looking towards downtown Los Angeles.

Michele Prichard, *Director, Common Agenda, Liberty Hill*

It is clear from the communities profiled here that expanded oil extraction operations—the first step in a long chain of oil production, transport, refining, and burning with documented deleterious health hazards at every stage—require urgent and decisive action by policy makers.

Regulators and lawmakers at the municipal, regional, state, and national levels all have a critical role to play in protecting the health and safety of residents. Yet, the involvement of so many different actors is one of the key challenges that have frustrated residents' efforts to get answers as oil-drilling operations expand and incorporate more hazardous techniques alongside conventional practices. As the community stories told here demonstrate, local residents often do not know to whom to turn for relief and response. Frequently, they have been shuffled between multiple offices in frustrating attempts to find the responsible agency.

There is a wide range of policy, zoning, regulatory, and enforcement tools to be considered by the many different agencies that have some jurisdiction and legal authority over oil operations in Los Angeles. Even a recent report by the L.A. Department of City Planning notes that "there is significant room for improvement in the way the City currently regulates and administers oil and gas activity" (Los Angeles Department of City Planning 2014).

The following section, while not exhaustive, highlights potential policy options that could provide greater public health and safety protections, more effective agency oversight, and a more accountable and open public process around current land use, permitting, and zoning practices concerning oil development. Here we distinguish between two major approaches: a "preventive" approach represents a fundamental shift to protecting public health by eliminating known hazards; a "mitigation" approach, on the other hand, seeks to reduce (but not eliminate) health hazards.

POLICY OPTIONS TO PROMOTE PREVENTION

Mounting scientific and public health evidence indicates that the toxic chemicals and related air emissions that accompany oil development—in both its conventional and enhanced forms—are hazardous to human health. Eliminating exposures to these hazardous chemicals is a primary prevention, providing the broadest, population-level health protections, especially for vulnerable populations with heightened sensitivity to such exposures, including children, pregnant women, the elderly, those suffering from chronic health problems, and low-income communities of color who face a "double jeopardy," impacted by multiple sources of pollution and socio-economic stressors (Morello-Frosch 2009). The following strategies represent significant departures from current philosophy and practice, in which communities often shoulder the burden of demonstrating harm, and they offer alternatives that promote precautionary action with the goal of preventing illness and injury and creating healthier communities.

STRATEGY #1: Prohibit Oil Drilling and Production Activities within Buffer Zones

Exposure to hazards can be significantly reduced by establishing a distance separation or setback—commonly referred to as a "buffer" zone—from homes, schools, businesses and other sensitive land uses. This form of community protection is already utilized locally and nationally. City Council leaders in Dallas set a precedent, recently approving a municipal ordinance requiring a 1,500-foot setback of oil drilling operations from residential and other sensitive land uses (City of Dallas 2013). Closer to home, the South Coast Air Quality Management District (SCAQMD) established a 1,500-foot radius for purposes of air monitoring and responding to odor complaints from oil drilling operations with a heightened level of response time and corrective action (SCAQMD 2013). The State of Colorado requires a public hearing before a well can be drilled within 1,000 feet of a high occupancy building, and the State of Maryland observes a 1,000-foot setback for oil wells (Richardson et al. 2013). Similarly, more than a decade ago, the California Air Resources Board issued recommendations to municipalities for health-protective buffer distances between sources of toxic air emissions to protect residential and sensitive populations (CARB 2005).

The alarming reports of severe health impacts in neighborhoods like University Park and Wilmington, and residents' concerns about safety from hazardous operations like those in Historic West Adams, provide significant merit to the concept of buffer zones that would separate these industrial sites from residential and sensitive land uses. In addition, the use of diesel trucks and unsightly diesel-powered equipment in neighborhoods poses another detriment to public health and the quality of life. The most precautionary approach would restrict—or even prohibit—both new and current oil extraction operations inside of the buffer zone, thereby better protecting the health and quality of life of adjacent neighborhood residents. Furthermore, a strong case can be made for a 1,500-foot buffer zone to provide for maximum safety, based on the precedent set by the City of Dallas and the SCAQMD's current monitoring practice.

STRATEGY #2: Establish Moratoriums, Interim Control Ordinances, and Bans on Hydraulic Fracturing and Other Well Stimulation Techniques

The City of Los Angeles has a number of planning tools available to restrict specific types of land uses, including moratoriums, interim control ordinances, and outright bans. In February 2014, a motion was introduced to place a moratorium on the practice of hydraulic fracturing (or "fracking") and related extraction technologies such as acidization, gravel-packing, and the use of waste-disposal injection wells. The proposal asserts that until it can be demonstrated that these methods do not pose environmental or health hazards, these types of operations should cease. While the SCAQMD's recent data shows a limited number of "fracking" incidents in the region, and none in the City of L.A. since June of 2013, the practice of acidizing wells and performing acid treatments of wells (also called "maintenance acidizing" by oil operators) is far more common and a cause for concern, especially for the residents who live and work near such sites (SCAQMD 2014). The proposed moratorium, especially if expanded to cover all forms of well activities, including acidization and maintenance acidizing, represents a preventive and health-protective approach that deserves serious consideration and public discussion.

Diesel trucks operate next to homes, emitting air toxics known to cause cancer.

Similar to a moratorium, an Interim Control Ordinance (ICO) is a planning tool that temporarily restricts a specific land use when there is concern about environmental or human health and safety hazards. With a general duration of six months, ICOs provide decision-makers with the time required to study an issue and recommend permanent and responsible land use solutions. For example, ICOs have been used to limit the establishment of medical marijuana retailers and fast-food restaurants, on the grounds that these land uses are over-concentrated in certain neighborhoods and pose a risk to public safety, community health, and quality of life. In the Wilmington-Harbor City Community Plan Area adjacent to the Port of L.A., an ICO was issued to halt the establishment and expansion of open storage yards that caused multiple neighborhood nuisances (e.g., dust, odors, vermin) until more permanent regulations could be drafted and instituted.

The use of diesel trucks and diesel-powered, unsightly equipment in neighborhoods poses another detriment to public health and the quality of life.

While the proposed City of Los Angeles moratorium implies a future end-point when a decision will be made based on scientific analysis, many municipalities have already implemented outright bans or permanent abolition of specific forms of oil production activities. In a high profile decision in December 2014, New York State Governor Andrew Cuomo announced a ban on hydraulic fracturing based on a State Department of Health report that cited "the weight of evidence from the cumulative body of information . . . demonstrates that there are significant uncertainties about the kinds of adverse health outcomes, and the likelihood of the occurrence of adverse health outcomes . . ." (New York State Department of Health 2014). Voters in communities throughout the country and state have taken to the polls to approve similar measures. Voters in the City of Denton, Texas approved a November 2014 ballot initiative to ban all hydraulic fracturing within city limits (Hennessy-Fiske 2014). In California in November 2014, voters in San Benito County approved a ban on well stimulation and enhanced recovery methods such as fracking and steam injection. San Benito's measure also imposed a ban on any new gas or oil drilling in areas zoned as residential or rural land uses (Cart 2014).

Maintenance trucks post signs indicating that they are transporting hazardous chemicals.

STRATEGY #3: Expand Role and Authority for Public Health Analysis in Permitting Process

Increasingly, community health is a primary consideration in local planning and land use decision-making. A growing body of evidence demonstrates that social, economic and environmental factors play an important role in determining the health status of populations. Poverty, unemployment, lack of access to healthy food and open space, and exposure to a variety of environmental contaminants all contribute to overall health at both the individual and community levels. The recent adoption of the Health and Wellness Element for inclusion in the City of Los Angeles' General Plan provides a powerful rationale for utilizing a public health framework for policy analysis, development, and decision-making related to oil drilling in Los Angeles.

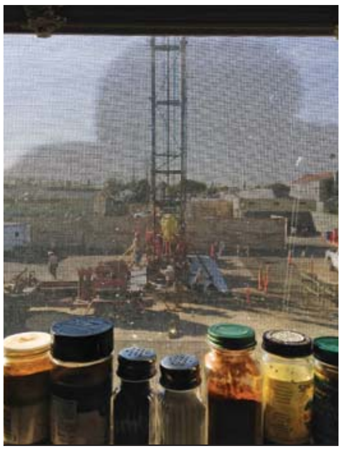
Engage the Los Angeles County Department of Public Health in permitting decisions.

Currently, the L.A. County Department of Public Health (DPH) oversees public health for both the City and County of Los Angeles. While DPH currently does not have a role in the approval of oil-drilling permits, it has recognized the adverse health impacts experienced by residents near the Allenco site. DPH's Preliminary Environmental Health Assessment report dated December 3, 2013, found that, "Petroleum-based compounds and associated odors from the Allenco facility are affecting the health and well-being of the adjoining community" (County of Los Angeles Department of Public Health 2013).

Angelo Bellomo, Director of Environmental Health for the Department, notes that "existing regulations do not adequately consider the risk to public health. The current regulatory system is inadequate, with many urban oil-drilling sites too close to sensitive land uses. We need to ensure the potential health impacts of proposed drilling sites are considered early on in the decision-making process" (A. Bellomo, personal communication 2014). Currently, the Department plays a "downstream" role in assessing and responding to health complaints from oil drilling, rather than an "upstream" role to ensure public health and safety through proactive prevention strategies. Upstream efforts that DPH could undertake include, but are not limited to: informing residents, policy makers and the media about health risks and protective policies associated with locating oil drilling adjacent to residential neighborhoods; and playing an advisory role in advance of project siting decisions.

Require Health Impact Assessments for new and expanded oil operations.

Health Impact Assessments (HIAs) are gaining significant attention as an effective way to bring a comprehensive public health framework to the evaluation of direct and indirect impacts of proposed land use projects



The view from a kitchen window of oil drilling operations next to homes at the Jefferson Drill Site in Historic West Adams.

and policies. HIAs have grown in use, particularly in vulnerable community project contexts, since they fill critical gaps left by current regulatory tools. HIAs have been conducted on a wide range of projects (e.g., housing, transportation, and major development projects) and policies (e.g., educational and social policy reforms) in order to better understand the full range of health benefits and risks related to air quality, noise, public safety, local business environment, mobility, jobs, etc. HIAs help decision-makers determine whether to proceed with a project, and if so, how best to mitigate its negative impacts. In the L.A. region, HIAs have been conducted and/or are being considered on the proposed Farmers Field stadium, the Long Beach Downtown Plan and Housing Element, and the I-710 expansion, to name a few. Given the potential for significant human health impacts, new and expanded oil-drilling activities should undergo Health Impact Assessments to document the risks alongside potential benefits. There is also a compelling case to be made for conducting HIAs on existing oil-drilling activities, given that many sites were authorized decades ago, when we had limited knowledge of the adverse health impacts of many pollutants already used. Especially in neighborhoods which have become more densely populated over time, while activities, technologies and the use of chemicals have significantly changed and intensified, it is imperative to have a complete picture of the current health, environmental, noise, public safety, job, and local business impacts associated with oil-drilling activities.

Recommended Performance Standards

- Require Environmental Impact Review and Health Impact Assessment for all projects applying for new wells, modified wells, and well expansion.
- Mandate the most protective measures in pollution prevention, best engineering practices, leak detection, Best Available Control Technology and Best Available Retrofit Control Technology.
- Limit the number of wells.
- Limit the hours of operation.
- Install enclosures or other technologies to trap fugitive emissions.
- Implement continuous monitoring of and reporting on emissions, air quality, and noise levels with results made publicly available and regularly reviewed by SCAQMD and DPH; thresholds should be set for when to investigate for leaks and equipment problems, and for when to cease operations until corrected.
- Develop emergency response plans, with plans for reassessment and upgrades.
- Issue protective warnings and notifications on-site, including posting of planned maintenance schedules so that sensitive populations can take precautions.
- Review periodically conditions, proper compliance, and the feasibility of improving operations at all sites.
- Implement long-term surveillance, monitoring, and reporting of health impacts among residents living adjacent to sites by DPH, including the addition of a question about proximity to oil wells in their current survey of Key Indicators of Health by Service Planning Area.
- Require a super-majority (e.g., 2/3) vote to approve any variance from standards by area or citywide commissions.

Exposure to hazards can be significantly reduced by establishing a distance separation or set-back—commonly referred to as a "buffer" zone.

Recommended Inspection, Monitoring, and Enforcement Practices

- Establish an Ombudsperson Office where all permitting, regulatory and enforcement entities can regularly coordinate on all aspects of oil drilling approvals, complaints, and compliance issues.
- Increase the frequency of unannounced inspections with costs to be defrayed through a fee structure borne by site operators.
- Increase air quality, water quality, and noise monitoring and testing, along with reporting and transparency about all emissions, including both routine and accidental leaks.
- Improve the response time and protocols of regulatory agencies to residents' complaints (especially fence-line neighbors), including ongoing efforts to update and strengthen SCAQMD rules 1148.1 and 1148.2.
- Require inspectors to bring appropriate air-quality testing equipment whenever responding to complaints on oil-production activities.
- Increase agency accountability and follow-through in response to residents' complaints and concerns, with specified next steps and clearly stated deadlines for corrective action.
- Use SCAQMD authority to impose heavy fines and penalties on serial violators, including increased fees to allow for more comprehensive inspection and enforcement.
- Use SCAQMD authority to deny permit renewals for serial violators.

POLICY OPTIONS TO MITIGATE PUBLIC HEALTH IMPACTS

In addition to strategies that seek to prevent health risks, there are many policy options that can mitigate and reduce current and potential health and safety concerns for residents. These mitigation strategies and safeguards would offer key public health benefits to residents affected by neighborhood drilling.

STRATEGY #1: Strengthen Performance Standards for Special Oil Districts

The City of Los Angeles has established Oil Districts (known as "O" Districts) in the Los Angeles Municipal Code Section 13.01. These are special geographic "overlay" zones with specific rules to govern oil drilling and production operations. The Department of City Planning's November 5, 2014 report notes that "Many of Section 13.01 provisions were established in the Code prior to the passage of the California Environmental Quality Act in 1970; therefore, they do not reflect current mandated environmental review requirements." In fact, the report describes how many of the current oil and gas regulations were established as early as the 1940s and 1950s. After review of the "O" Districts, the L.A. Department of City Planning stated, "Updates to the code section have not kept time with the changing industry, economy, urban environment, or the City's evolving information management strategies" (Los Angeles Department of City Planning 2014). With most of the provisions of the "O" District standards now decades old, new regulations to govern future oil development are desperately needed. Moreover, a comprehensive review of all existing "O" District boundaries and compliance with permitting standards and/or conditional use permits would be prudent. Drilling sites that have introduced changes in operations since their original permit approvals should be reevaluated by regulatory authorities based on existing operations rather than grandfathered in under old permits.

STRATEGY #2: Strengthen Comprehensive Inspection, Monitoring and Enforcement

A patchwork of regulatory and permitting authorities contributes to confusion, delays and lack of responsiveness to resident concerns.

Are we ready to spur innovation towards a just transition to a clean, renewable, and safe energy future?

Especially as the industry adopts new, advanced technologies to increase oil production at locations originally permitted long ago, it is critical that oversight be systematic and coordinated to ensure that the health and safety of residents are safeguarded. The current situation is riddled with gaps in jurisdiction, legal authority and poor enforcement of inadequate regulations, resulting in delayed responses, conflicting information, and inaction around resident concerns.

STRATEGY #3: Strengthen Transparency, Information Access and Public Engagement

Current information-sharing practices by local, regional, and state agencies for local residents are in need of serious improvement. Originally developed to respond to producers' concerns, transparency and public engagement measures are not responsive to the legitimate health and safety concerns of nearby residents and the community at large. While procedures for community notification, information sharing, public participation, and input to the policy and regulatory process vary across agencies, pervasive deficiencies include the lack of any public hearing; insufficient advanced notice of permit requests; public hearings held at inconvenient times of day and at inconvenient locations for community residents; notifications and meetings in English only, excluding monolingual or bilingual residents; notifications shared only with a subset of impacted and concerned residents; lengthy advanced notice requirements for information requests by residents; and other barriers for accessing information (such as the requirement to access information only during standard business hours). And while recent legislation, most notably California State Senate Bill 4, has improved industry reporting and the accessibility of information by the public, the use of the "trade secrets" provision to prevent disclosure of the chemicals used in oil drilling and production is very troubling (California Senate Bill 4, 2013).

Recommended Transparency, Information Access, and Public Engagement Practices

- Expand citizen oversight and/or inclusion in review panels.
- Increase the advanced notice of public meetings (to a minimum of one month).
- Share meeting notices with property owners and residents, including renters, living or studying within 1,500 feet of an oil extraction site.
- Provide all notices in English, Spanish and other appropriate languages, and make appropriate translation available at all public meetings; provide interpretation for neighborhoods where other languages are commonly spoken.
- Hold meetings on evenings and weekends when residents are not as likely to be at work.
- Hold meetings in the impacted community (rather than at more remote agency offices).
- Schedule appointments with residents who wish to obtain records during non-business hours to accommodate resident work schedules.
- Reduce the advanced period for residents to request information to one week or less.
- Require permit applicants to provide full disclosure of all chemicals and processes used in oil drilling and production operations.
- Continue work to amend SCAQMD Rules 1148.1 and 1148.2 to ensure that reporting and notification requirements are strengthened for oil drilling, maintenance, and production wells, and ensure that complainants receive follow-up analysis and reports on corrective action from SCAQMD and other agencies.

An aggressive commitment to rooftop solar installations in Los Angeles will expand the local economy, accelerate the transition to clean energy, and lead to dynamic job growth.

TOWARD A HEALTHY AND SUSTAINABLE LOS ANGELES

This report highlights the changes in the oil drilling and development landscape that have taken place in Los Angeles since the original permitting of many older pumps. In many instances, drilling operations now take place directly adjacent to residential neighborhoods and sensitive land uses. Many of these areas are densely populated with high proportions of low-income residents, people of color, and renters. These communities also bear disproportionate pollution exposure burdens that make them more vulnerable to the health hazards resulting from oil-drilling operations.

The City of Los Angeles has emerged as a leader in adopting far-reaching environmental, land use, and public health policies. Innovative sustainability policies at the city's proprietary agencies—the Port of Los Angeles, the Los Angeles World Airports, the Department of Water and Power—as well as recent initiatives such as the aforementioned Health and Wellness Element, Mayor Garcetti's Sustainable City pLAn and Re:Code LA (a five-year initiative to systematically update and revise the city's outdated zoning code) represent opportunities for rethinking the way that the City governs planning and land use activities that directly impact the quality of life and well-being of residents and businesses.

Similarly, the State of California has demonstrated unprecedented leadership in setting ambitious and visionary goals to affect climate change by significantly reducing greenhouse gas emissions from fossil fuels. The Global Warming Solutions Act of 2006, along with a suite of other innovative policies for investing in carbon reduction strategies that can also deliver social equity and economic development benefits, is breaking new ground in the fight to address climate change. Recent carbon-reduction targets announced in early 2015 by the Governor and other Legislators for 2030 and 2050, and highlighted in Mayor Garcetti's Sustainable City pLAn, promise to accelerate the pace of change.

We are on the threshold of a decisive moment: Will we perpetuate land use and energy policies which support the expansion of a dirty, fossil-fuel based economy with damaging health, neighborhood, and environmental consequences?

Or, are we ready to spur innovation towards a just transition to a clean, renewable, and safe energy future—not only through investments in energy and water conservation, mass transit, and solar generation—but through a reformed land use policy which recognizes and limits the resulting health inequities and quality of life burdens suffered by far too many of its inhabitants?

Now is the time to engage in that public discussion.

The time has come to move toward a preventive approach that protects human health while advancing us towards a renewable, clean, sustainable, and green economy.

Sustainability Policies Passed by the City of Los Angeles and Proprietary Agencies

CITY DEPARTMENT/AGENCY	PROGRAM TITLE	LINK TO DOCUMENTS
Port of Los Angeles	Clean Air Action Plan & Clean Truck Program	http://www.cleanairactionplan.org/
Los Angeles World Airports	LAWA Sustainability Plan	http://tinyurl.com/LAWA-Sustainability-Plan
Los Angeles Department of Water and Power	LADWP Sustainability Plan	http://tinyurl.com/LADWP-Sustainability-Plan
Los Angeles Department of City Planning	PLAN for a Healthy Los Angeles	http://healthyplan.la/
Office of Mayor Eric Garcetti	Sustainable City pLAn	http://plan.lamayor.org/

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Exhibit 4 of 13 - Ferrar 2021. It's time to stop urban oil drilling LA

It’s Time to Stop Urban Oil Drilling in Los Angeles - FracTracker Alliance

Kyle Ferrar, MPH

/September 14, 2021 / 5 minute read

view map & data

Overview

This report finds that disparate counts of drill sites in Los Angeles County, California, are located in marginalized communities. Additionally, a story map of infrared camera footage shows emissions otherwise invisible to the naked eye in Los Angeles urban drilling sites.

When people think of Southern California, images of palm trees, beaches, boardwalks, and nightlife come to mind. Unless you are an Angeleno, you may not associate oil drilling and petroleum extraction with the Golden State.

In truth, Los Angeles is ground zero for urban drilling.

Oil companies drill wells and use toxic industrial chemicals on well sites just feet away from homes, schools, and medical facilities. These urban drilling sites degrade air quality and expose communities to toxic and carcinogenic emissions. Using state-of-the-art optical gas imaging (OGI) cameras, FracTracker Alliance—in collaboration with Earthworks’ Community Empowerment Project—has filmed emissions from oil wells in Los Angeles. The overwhelming amount of existing public health research (including recently published epidemiological reports from Stanford University and The University of California – Berkeley linking adverse birth outcomes [Tran, et al. 2020, Gonzalez, et al. 2020] and University of Southern California/Occidental College report on lung function), has confirmed these emissions are the source of a wide variety of health impacts for Frontline communities.

Previous FracTracker Alliance reports show that Frontline communities in the most heavily drilled areas of Southern California, and specifically those in Los Angeles, are predominantly low-income, non-white, and/or Latino. While city blocks have replaced an amazing number of oil and gas wells, a substantial number of extractive sites persist in these marginalized areas. FracTracker has worked to publish this data to support Frontline communities’ organizing in Los Angeles who have made major accomplishments so far this year.

New policy proposals could shift Southern California from a major source of greenhouse gases into a leader in our fossil-free future. The City of Los Angeles is currently considering zoning regulations to phase out oil drilling in response to a five-year grassroots campaign led by directly affected residents and advocates. The City Council also called on the California Department of Geological Energy Management (CalGEM) to expedite the closure of the Aliso Canyon gas storage facility in Porter Ranch, following its massive blowout in 2015. Additionally, Culver City passed a motion to phase out oil drilling in the Inglewood Field and to clean up wells in surrounding areas within five years!

Now, the Los Angeles County board of supervisors will vote on September 15th to phase out extraction in the unincorporated areas of the county.

Take action here to call on Los Angeles County officials to follow the leadership of local municipalities and phase out oil wells in the unincorporated regions.

While certain cities in Los Angeles have taken steps to reduce extraction, the County of Los Angeles also has the opportunity to address much of the drilling in the basin. The County manages about 1,700 wells located on unincorporated lands. A map of well locations by County Supervisorial Districts can be found below. Population counts were calculated for each district and demographic profiles of the most impacted communities were assessed. The methods used in this analysis can be found in Appendix A, at the end of this article.

Los Angeles County Oil and Gas Wells

This interactive map illustrates the locations of oil and gas wells in Los Angeles County. The map includes boundaries of incorporated city areas overlaid with operational oil and gas wells. Users can toggle different layers in the map on and off to show the status of oil and gas wells, or the location of operational wells in incorporated vs unincorporated areas. View the map “Details” tab below in the top right corner to learn more and access the data, or click on the map to explore the dynamic version of this data. Data sources are also listed at the end of this article. In order to turn layers on and off in the map, use the Layers dropdown menu.

View Full Size Map | Updated 9/13/21| Map Tutorial

The analysis shows that for the majority of Los Angeles County districts, a disproportionate number of drill sites are located in marginalized communities.

The demographics of Angelenos living near operational oil and gas well are more Latinx and non-white than the rest of the county. The most substantial disparities are located in Districts 1, 2, 4, and 5, where the majority of operational wells are also located. In District 2, the unincorporated communities bearing the brunt of exposure from oil are over 65% non-white, and nearly 50% Latino. The most impacted communities in District 4 are over 55% non-white, and over 55% Latino. Least impacted by this trend is District 3, which has the lowest population density and one of the lowest counts of operational oil and gas wells. Notably, operational well numbers in District 1 are lowest because the majority of the district is incorporated city lands. Regardless, the most impacted communities in District 1 are nearly 60% non-white, as well as 55% Latino.

Supervisor District	District 1 (Unincorporated areas only)	District 2 Baldwin Hills/Inglewood Oil Field (excluding Culver City)	District 2 (Unincorporated areas only excluding Inglewood Oil Field)	District 3 (Unincorporated areas only)	District 4 (Unincorporated areas only)	District 5 (Unincorporated areas only)
Active wells Total	0	659	82	13	43	193
Idle wells Total	8	203	74	11	88	294

Table 1. Well Counts of urban drilling in unincorporated areas of Los Angeles County Districts 1-5.

Filming Toxic Emissions at Oil Wells in Los Angeles

In the fall of 2019, FracTracker collaborated with Earthworks to visit urban drilling sites in Los Angeles, at the request of Frontline communities.

Fugitive and uncontrolled volatile organic compound (VOC) emissions were filmed by a certified thermographer with a Forward Looking Infrared (FLIR) GF320 camera that uses optical gas imaging (OGI) technology. OGI technology allows the camera to film and record visualizations of VOC emissions based on the absorption of infrared light. It is the exact same technology required by the U.S. EPA under the rule for new source performance standards, and by the California Air Resources Board for Leak Detection and Repair (LDAR) to properly inspect oil and gas infrastructure. The video is in greyscale, and can appear grainy when the camera is being operated in high sensitivity modes, which is sometimes necessary to visualize certain pollution releases. The footage clearly shows the presence of a range of VOCs, methane, and other gases that are otherwise invisible to the naked eye.

The descriptions preceding each video explain what the trained camera operator saw and documented. Emissions sources included a variety of equipment and infrastructure on the wellpads, including the oil wells themselves. The emissions at these sites are typical of oil and gas wells throughout California and Los Angeles. These 17 sites visited over just a few days represent a very small sample of the tens of thousands of well sites in Los Angeles.

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The Take Away

While the state and Newsom's Administration delays on instituting any public health measures that would give relief to the largely marginalized communities most impacted by California's extractive industry, Los Angeles is ready to lead.

Los Angeles County and the cities of Los Angeles and Culver City are moving forward with measures that will greatly benefit the health of Angelenos. With this momentum, now is the time to urge other cities that make up the greater Los Angeles basin to move forward in solidarity to protect the health of Southern California's Frontline communities.

For more information on how you can make your voice heard, visit the Los Angeles chapter of Physicians for Social Responsibility's (PSR-LA) website where you can sign up for their newsletter to stay informed about local actions!

References & Where to Learn More

Feature photo from Natural Resources Defense Council

Appendix A

Methods

In this article, we conducted spatial analyses using the demographic data of Frontline communities and the locations of oil and gas wells in Southern California. This assessment used CalGEM data (updated 3/1/21) to map the locations of operational oil and gas wells and permits, as shown above in Figures one through five. GIS analyses were completed using ESRI ArcGIs Pro Ver. 2.6.1, with data projected in NAD83 California Teale Albers, and were limited to the unincorporated areas of Los Angeles County districts. Unincorporated areas were determined using datasets of county districts from L.A. County Enterprise GIS Hub and state datasets of city boundaries from California geoportal.

Block group level "census designated areas" from American Community Survey (2013-2018) demographics were used to estimate counts of Californians living near oil and gas extraction activity. Census block groups were clipped using the buffered datasets of operational oil and gas wells. A uniform population distribution within the census blocks was assumed in order to determine population counts. Census demographics and total population counts were scaled using the proportion of the clipped block groups within the setback area (Areal percentage = Area of block group within established exposure distances of an operational well / Total area of block group).

This conservative approach provided a general overview of the count and demographics of Californians living near extraction operations, but the results do little to shed light on the most impacted Frontline communities, specifically, urban areas with dense populations near large oil fields. More granular analyses at the local level have been conducted by FracTracker Alliance recently, and can be found in the People and Production report on the FracTracker Alliance website.

Datasets utilized:

1. CalGEM AllWells.csv dataset. https://www.conservation.ca.gov/calgem/Online_Data. Downloaded 7/3/21.
2. California Counties and City Boundaries. California Department of Tax and Fee Administration. https://gis.data.ca.gov/datasets/CDTFA::city-and-county-boundaries/about. Downloaded 7/15/21.
3. Los Angeles County Supervisorial Districts. County of LA. https://geohub.lacity.org/datasets/lacounty::supervisorial-districts-2011/about. Downloaded 6/12/21

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Your donations help fund the sourcing and analysis of new data so that we can keep you informed and continually update our resources.

Please donate to FracTracker today as a way to advocate for clean water, clean air, and healthy communities.

Exhibit 5 of 13 - Gonzalez 2022. Upstream oil and gas production and ambient air pollution in California

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Upstream oil and gas production and ambient air pollution in California

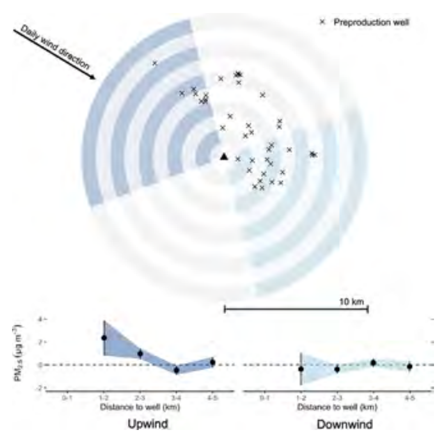
David J.X. Gonzalez [a,b,*], Christina K. Francis [c], Gary M. Shaw [d], Mark R. Cullen [e,1], Michael Baiocchi [f], Marshall Burke [g]

[a] Department of Environmental Science, Policy and Management and School of Public Health, University of California, Berkeley, Berkeley, CA 94720, USA
[b] Emmett Interdisciplinary Program in Environment and Resources, Stanford University, Stanford, CA, USA
[c] Program in Environmental Science and Studies, Johns Hopkins University, Baltimore, MD, USA
[d] Department of Pediatrics, Stanford University, Stanford, CA, USA
[e] Founding Director of the Stanford Center for Population Health Sciences, USA
[f] Department of Epidemiology and Population Health, Stanford University, Stanford, CA, USA
[g] Department of Earth System Science, School of Earth, Energy and Environmental Sciences, Stanford University, Stanford, CA, USA

HIGHLIGHTS

- Oil and gas wells have been linked to adverse health, but mechanisms not well understood.
- Applied a quasi-experimental design with daily air pollution and oil production data
- We leveraged wind direction as source of exogenous variation for exposure to wells.
- Upstream oil and gas production emitted air pollutants at concentrations that may be harmful.
- Evaluated proximity as an appropriate indicator of air pollution exposure from wells

GRAPHICAL ABSTRACT



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ABSTRACT

Background: Prior studies have found that residential proximity to upstream oil and gas production is associated with increased risk of adverse health outcomes. Emissions of ambient air pollutants from oil and gas wells in the preproduction and production stages have been proposed as conferring risk of adverse health effects, but the extent of air pollutant emissions and resulting nearby pollution concentrations from wells is not clear.
Objectives: We examined the effects of upstream oil and gas preproduction (count of drilling sites) and production (total volume of oil and gas) activities on concentrations of five ambient air pollutants in California.
Methods: We obtained data on approximately 1 million daily observations from 314 monitors in the EPA Air Quality System, 2006-2019, including daily concentrations of five routinely monitored ambient air pollutants: $PM_{2.5}$, CO, NO_2, O_3, and VOCs. We obtained data on preproduction and production operations from Enverus and the California Geographic Energy Management Division (CalGEM) for all wells in the state. For each monitor and each day, we assessed exposure to upwind preproduction wells and total oil and gas production volume within 10 km. We used a panel regression approach in the analysis and fit adjusted fixed effects linear regression models for each pollutant, controlling for geographic, seasonal, temporal, and meteorological factors.

* Corresponding author at: 108 Hilgard Hall, University of California, Berkeley, Berkeley, CA 94720, USA.
E-mail address: djxgonz@berkeley.edu (D.J.X. Gonzalez).
[1] Retired.

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Results: We observed higher concentrations of $PM_{2.5}$ and CO at monitors within 3 km of preproduction wells, NO_2 at monitors at 1-2 km, and O_3 at 2-4 km from the wells. Monitors with proximity to increased production volume observed higher concentrations of $PM_{2.5}$, NO_2, and VOCs within 1 km and higher O_3 concentrations at 1-2 km. Results were robust to sensitivity analyses.
Conclusion: Adjusting for geographic, meteorological, seasonal, and time-trending factors, we observed higher concentrations of ambient air pollutants at air quality monitors in proximity to preproduction wells within 4 km and producing wells within 2 km.
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1. Introduction

Recent studies have found that residing in proximity to oil and gas wells is associated with adverse cardiovascular, psychological, perinatal, and other health outcomes (Casey et al., 2015, 2018; Currie et al., 2017; Denham et al., 2021; McKenzie et al., 2014, 2018, 2019; Tang et al., 2020; Whitworth et al., 2017; Willis et al., 2021). Studies in California have found higher risk of preterm birth and low birthweight with exposure to upstream oil production, as well as impaired lung function and higher asthma prevalence (Gonzalez et al., 2020; Johnston et al., 2021; Shamasunder et al., 2018; Tran et al., 2020). Several possible mechanisms have been hypothesized for the observed associations between proximity to wells and adverse health outcomes, including emissions of ambient air contaminants during various stages of upstream oil and gas production (Adgate et al., 2014; Allshouse et al., 2019; Gonzalez et al., 2020; Johnston et al., 2019; McKenzie et al., 2012). There is a potential for widespread risk of exposure to air pollutant emissions from upstream oil and gas development, with an estimated 17.6 million U.S. residents, including 2.1 million Californians, living within 1.6 km (1 mile) of at least one active well (Czolowski et al., 2017).

Despite widespread potential exposure to wells and reported health risks, the effects of upstream oil and gas production on ambient air quality are still not well understood (Johnston et al., 2019). Under the Clean Air Act and its amendments, local regulatory agencies are responsible for maintaining networks of in situ air pollution monitors (Grainger et al., 2017). Agencies routinely monitor criteria air pollutants, which are statutorily regulated under the Clean Air Act and which include fine particulate matter with an aerodynamic diameter less than 2.5 μm ($PM_{2.5}$), carbon monoxide (CO), nitrogen dioxide (NO_2), and ozone (O_3). Other hazardous pollutants are also routinely monitored, including non-methane volatile organic compounds (VOCs) such as acetaldehyde, benzene, ethylbenzene formaldehyde, n-hexane, toluene and xylene. In prior studies, such as in situ monitoring campaigns conducted in California, Colorado, and Texas, investigators have reported elevated concentrations of $PM_{2.5}$, CO, NO_2, O_3, and VOCs near wells (Allshouse et al., 2019; Arbelaez and Baizel, 2015; Garcia-Gonzales et al., 2019a; Schade and Roest, 2016, 2018). Sources of $PM_{2.5}$ emissions associated with upstream oil and gas production may include combustion of diesel fuel from on-site equipment and heavy trucks, dust from construction sites and unpaved roads, and secondary formation in the atmosphere (Adgate et al., 2014); emissions of CO and NO_2 may also be associated with fossil fuel combustion in vehicles and off-road equipment (Holloway et al., 2000; Jackson et al., 2014); O_3 may be formed as a secondary pollutant in photochemical reactions involving nitrous oxides (such as NO_2) and VOCs in the presence of sunlight (Mauzerall et al., 2005; Rodriguez et al., 2009).

Studies have found elevated concentrations of harmful pollutants near oil and gas wells (Garcia-Gonzales et al., 2019b). However, prior studies have been geographically and temporally constrained and often do not mirror methods applied by population health researchers. In particular, exposure characterization is often spatial in nature, whereas population health researchers often seek to exploit temporal variation to isolate the role of exposure to oil and gas wells from exposure to other spatially correlated activities that may affect pollution and health (Currie et al., 2017; Willis et al., 2021). Additionally, the unique geological conditions of California may constrain external validity of air quality studies that investigate oil and gas production-related emissions in other settings (Garcia-Gonzales et al., 2019a). Population health studies investigating exposure to upstream oil and gas production typically use proximity to wells as the indicator of exposure without directly measuring concentrations of air pollutant emissions or other potential hazards, such as noise and water pollution (Casey et al., 2015; Currie et al., 2017; Gonzalez et al., 2020; McKenzie et al., 2014; Rasmussen et al., 2016; Tang et al., 2020; Tran et al., 2020; Willis et al., 2021). Improved understanding of pollutants emitted during upstream oil and gas production, including the classes of pollutants emitted (or secondarily produced) and the distances to which they are transported could help population health scientists more accurately parameterize exposure assessments and determine which aspects of exposure to production activities may adversely affect human health.

In our prior study (Gonzalez et al., 2020), we found that proximity to wells was associated with higher preterm birth risk, but we were not able to measure specific chemical pollutants parents were potentially exposed to during their pregnancy, or to separate proximity to wells from other activities that may also affect preterm birth risk. Our objectives in the current study were to examine how upstream oil preproduction and production activities affected ambient air quality in California from 2006 to 2019, with the aim of informing population health studies of exposure to upstream oil and gas production. We investigated whether marginal changes in preproduction and production activities resulted in increased concentrations of $PM_{2.5}$, CO, NO_2, O_3, and VOCs. Where we observed marginal increases in pollutant concentrations with proximity to wells, we also aimed to determine the distance at which elevated concentrations decay to background levels. To address these objectives, we applied a quasi-experimental design using a panel of publicly available air quality monitoring data.

2. Methods

2.1. Study design

We constructed a panel dataset with repeated daily measures of ambient air pollutant concentrations as well as upstream oil and gas production across California from January 1, 2006, to December 31, 2019. We made use of geospatial and temporal variation in oil and gas extraction activities, including well preproduction (defined as the interval between spudding, or initiation of drilling, and completion) and production (total monthly volume of oil and gas produced), and leveraged daily variation in wind direction as a source of exogenous variation. The type and magnitude of emissions may vary by stage due to differences in activities related to preproduction and production, and the intensity of well pad activity varies within each stage (Allshouse et al., 2017). For each monitor, we assessed daily exposure to upwind wells in preproduction and production during the study period. In the current study, we did not assess exposure of any human populations; rather, we assessed exposure of air quality monitors as a surrogate receptor. Then we used a fixed effects regression approach to assess the effect of exposure to preproduction and producing wells on the concentrations of each pollutant, accounting for geographic, seasonal, and time-trending, and meteorological factors.

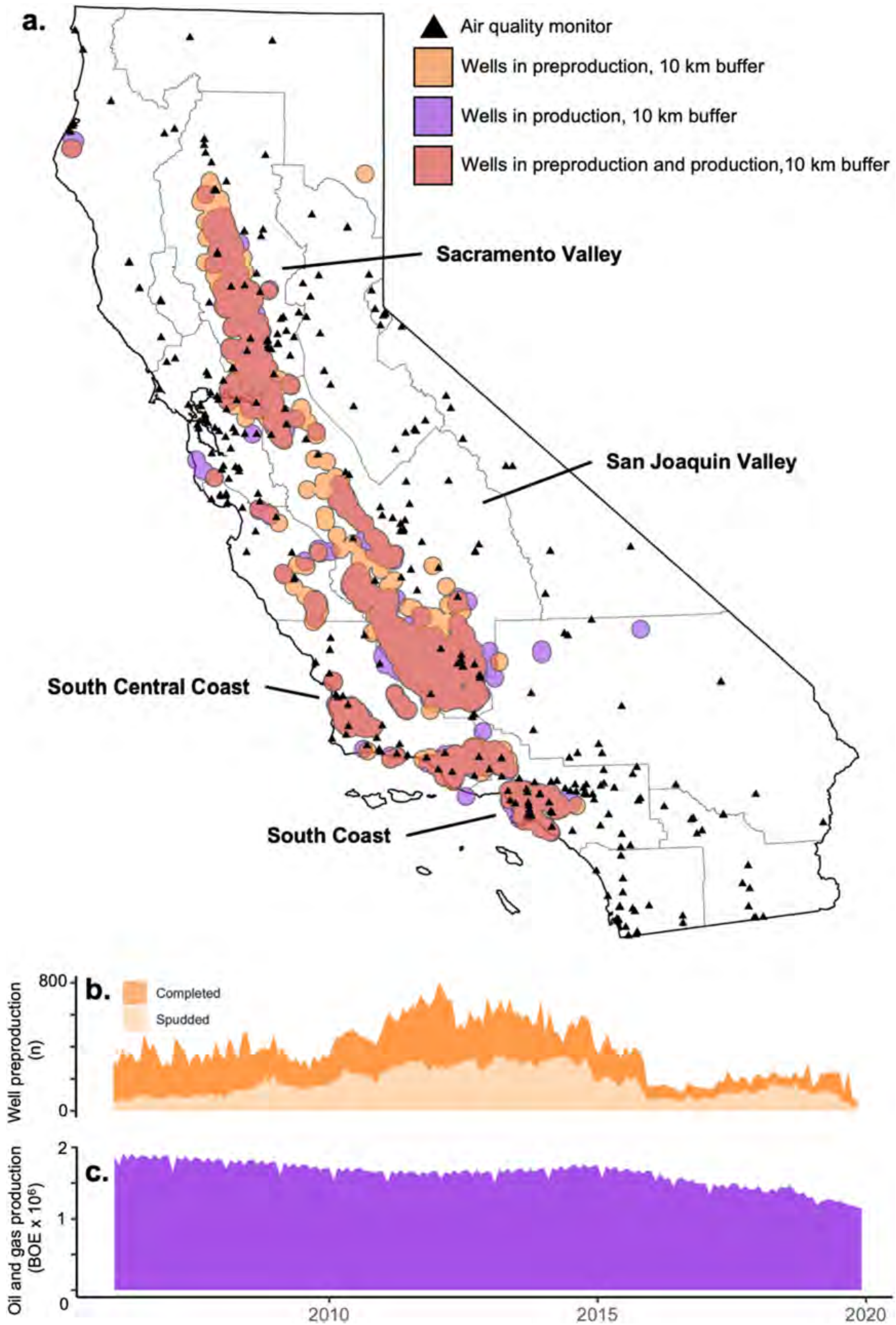

Fig. 1. (a) A map of the study region, showing air basins, air quality monitor locations, and 10 km buffers around wells in preproduction (orange) and production (purple), as well as the overlap (red). (b) Count of wells spudded and completed by month across California, including recompletions of previously drilled wells. (c) Total oil and gas production by month for all wells in California, reported as million barrels of oil equivalent (BOE).

2.2. Data

We obtained air quality data from the U.S. Environmental Protection Agency (EPA) Air Quality System (AQS). This dataset comprised daily measurements of seven air pollutants, with daily mean concentrations of $PM_{2.5}$ (μg m^{-3}) as well as daily max concentrations of CO (ppm), NO_2 (ppb), O_3 (ppb), and non-methane VOCs (ppb C). In all analyses, the unit of observation was the pollutant concentration at each monitor for each day, or the monitor-day. We included data for all 314 AQS monitors in California that were operating during the study period and that monitored for the five pollutants of interest (Fig. 1). Missing air pollution data were omitted from the analyses; we did not impute missing air pollution data. Due to the sparse monitoring of VOCs compared to other pollutants, we included data on VOC measurements for 1999-2005; we excluded pre-2006 measurements for other pollutants because data for wildfire smoke plumes, described below, were not available before 2006. Air qualtity monitors detected and measured non-methane VOC concentrations via the EPA Method TO-3 for ethylbenzene, n-hexane, toluene, benzene, and ethylene using cryogenic preconcentration techniques, gas chromatography, and flame ionization detection. Xylene concentrations were estimated using preconcentration techniques, gas chromatography, and Saturn 2000 ion mass spectrometry. Acetaldehyde and formaldehyde concentrations were measured using 2,4-dinitrophenylhydrazine (DNPH) silica gel cartridges, an O_3 scrubber, and ultraviolet absorption spectroscopy.

Data on the oil and gas wells, including development dates and monthly production volume, was obtained from the California Geologic Energy Management Division (CalGEM) and Enverus, a private data aggregation service. The analytic dataset included 38,157 wells that were in the preproduction and 90,697 wells in production in California during the study period (Table S1). We defined the preproduction stage of the well as starting with the reported spud date (when drilling begins) and ending with the completion date. We assessed monitors as exposed to proximate preproduction wells on days when the well was between the dates of spudding and completion. Preproduction wells were included in the study if the preproduction interval (spudding to completion) occurred during the study period. For wells with missing data for spud date, we assumed that the preproduction interval began 30 days before completion; for wells missing completion date, we assumed the preproduction stage ended 30 days after spudding. Wells missing both spud and completion dates were assumed to have been drilled outside the study period; since the record dates to the late 19th century, we expected there to be missingness in these variables for wells drilled prior to 1999. Wells in the production stage were included for all sites with any reported oil or gas production during the study period. Because oil and gas are frequently produced from the same wells, we used a combined metric of oil and gas production reported as barrels of oil equivalent (BOE). The dataset comprised 8,064,549 well-month observations of a total of approximately 3.8 billion BOE.

We obtained meteorological data from the North American Regional Reanalysis (NARR), a product developed by the National Centers for Environmental Prediction. This dataset included modeled daily mean wind direction and speed, reported as vectors (u and v), as well as observations of mean daily surface temperature (°C) and total daily precipitation (mm). There were no missing estimates for these meteorological variables. We also obtained administrative shapefiles for air basins across the state from the California Air Resources Board (CARB). We used data from the 2010 decennial census to determine whether monitors were located in urban areas (with 50,00 or more residents) or urban clusters (with 2500-50,000 residents) compared with rural areas, which comprise all other areas. To control for potential effects of wildfire smoke on daily concentrations ambient air pollutants, we used data on the daily location of wildfire smoke plumes from the Hazard Mapping System of the National Oceanic and Atmospheric Administration (NOAA), which assessed the number of overhead smoke plumes at the zip code level (Schroeder et al., 2008).

2.3. Exposure assessment

We constructed a panel dataset where, for each monitor and each day with a pollutant observation, we summed (a) the number of upwind wells in preproduction and (b) the total volume of upwind oil and gas production (BOE) in 1 km increments out to 10 km (Fig. 2). We determined the wind direction for each monitor and day from the u and v vector components from the NARR wind product. The resultant of the u and v vector components conveys wind direction and speed (magnitude). Preproduction and production wells that intersected the upwind quadrant on each day for each monitor comprised the primary exposure variables; wells outside the quadrant were excluded in the primary analyses.

As sensitivity analyses, we also assessed exposure to wells in the downwind quadrant as a placebo exposure. Additionally, we assessed exposure to all preproduction wells and production volume in 1 km annuli (or rings) radiating out from the monitor, i.e., without taking wind into account.

The receptor in our exposure assessment was the air quality monitor; this study did not consider any human receptors or health outcomes. Our aim was to use air monitors as a proxy for the residential receptors typically targeted in population health studies that assess exposure to oil and gas wells.

2.4. Identification strategy

We leveraged daily variation in wind direction as a plausibly exogenous source of variation, uncorrelated with well preproduction and production activities as well as other sources of pollution. This strategy allowed us to, by design, isolate the marginal contributions of additional preproduction wells and production volume to ambient air pollutant concentrations.

2.5. Statistical analyses

We used adjusted fixed effects linear regression models to assess how marginal changes in (a) the count of wells in preproduction or (b) the volume of oil and gas production affects concentrations of each observed pollutant ($PM_{2.5}$, CO, NO_2, O_3, and VOCs). For each combination of pollutants and well stage (preproduction or production), we fit the following model:

$$Y_{md} = U_{mda} + D_{mda} + O_{mda} + C_{md} + \gamma_{md} + \delta_{by} + e_{md},$$

where Y is the observed daily concentration of the pollutant at monitor m on day d; U is a vector of either the (a) upwind count preproduction wells or (b) upwind sum oil and gas production on day d in annulus a (0-1 km, 1-2 km, … 9-10 km) radiating from monitor m; D is similar to U but for downwind wells; O is also similar to U, but were wells in the two quadrants orthogonal to the upwind quadrant (i.e., lateral wells); C is a vector of covariates (day of week, precipitation in mm, temperature in °C, wind speed in ms^{-1}, and the count of overhead smoke plumes) at monitor m on day d; γ is a fixed effect for monitor by month, n; δ is a fixed effect for air basin, b, by year, y; *and e* is an error term representing unmodeled sources of variation in pollution at monitor m on day d. We fit additional models with polynomial terms for each exposure bin to examine whether the response was nonlinear.

We compared the point estimates for upwind wells with downwind placebos. As sensitivity analyses, we also modified the fixed effects in the model, using monitor-by-year and air basin-by-month-by-year fixed effects in the model. Additionally, we fit models as described above in the primary analysis but using exposure assessment data that did not take wind into account (i.e., the sum of all preproduction wells or production volume within each annulus). Finally, as an additional sensitivity analysis for co-exposure to wildfire smoke, we fit models

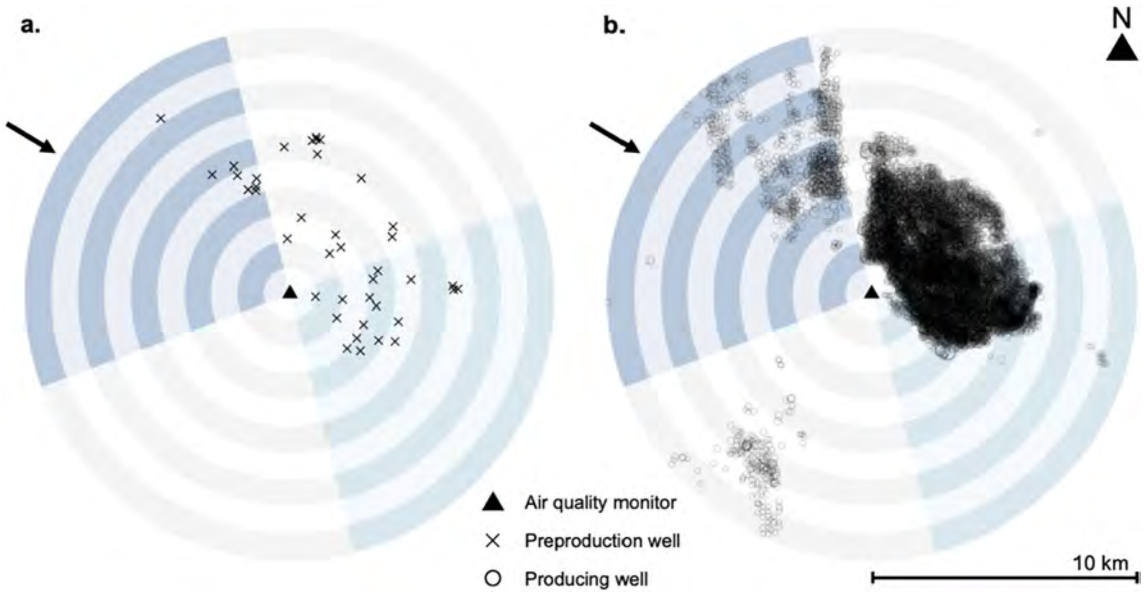

Fig. 2. A visualization of the exposure assessment method at a monitor located in Bakersfield, California, using sample data from July 1, 2009, when the wind was blowing from the northwest (arrow). For each monitor-day, we assessed exposure to (a) the count of wells in preproduction and (b) the total volume of oil and gas produced upwind (darker shaded area) of the monitor. As a placebo test, we assessed exposure to wells downwind (lighter shade) of the monitor.

for $PM_{2.5}$ where monitor-day observations that had >0 smoke plumes overhead were omitted.

In total we fit 27 models, and, as the primary analysis, we focused on the adjusted fixed effects regression models for exposure to preproduction wells and production volume. In particular, we were interested in the point estimates for exposure to upwind wells and production within 5 km of the monitor.

All data preparation and analyses were conducted using R v. 4.0 (R Core Team, 2020).

3. Results

3.1. Descriptive statistics

The analytic dataset comprised 1,058,230 daily observations of the five pollutants from 314 monitors across California collected from 2006 to 2019, with additional observations for VOCs from 1999 to 2005 (Table 1). Most (208) monitors were located in urban areas and approximately half (158) were in the four air basins with the majority of oil and gas wells (96.4%) and production (87.2%): Sacramento Valley, San Joaquin Valley, South Central Coast, and South Coast (Table S1). Not all monitors collected data for all pollutants. The majority (79.5%) of monitor-days included observations for O_3, with 43% of monitor-days including data for NO_2 and $PM_{2.5}$. Some 31% of monitor-days included CO observations and 8.9% included observations of VOCs. Among the 94,349 monitor-days with an observation for VOCs, 39.3% were in the San Joaquin Valley and 12.8% were in the South Coast basin, both basins where most oil and gas wells were concentrated. For each pollutant, there were more observations at monitors more than 10 km from wells than monitors near wells. More observations were collected in the later years of the study period compared to earlier in the study period. The number of monitors in operation throughout the study period was relatively consistent from year to year; the minimum number of monitors in operation was 223 in 2006 and the maximum was 245 in both 2012 and 2014, with a median of 239 (Fig. S4). The number of monitors that assessed $PM_{2.5}$ concentrations increased throughout the study period. Concentrations of pollutants at monitors within 10 km of wells were similar to the concentrations at monitors further away (Table 1).

Wells in all production stages were concentrated in the San Joaquin Valley, which includes Kern County, with substantial production in the South Coast air basin, which includes Los Angeles County (Table S1). Among the 314 monitors included in the analytic dataset, 79 (25.2%) were within 10 km of at least one oil or gas well, 33 (10.5%) were within 3 km, and 11 (3.5%) were within 1 km. Of the monitor-days included in the analysis, 46,477 (4.4%) were exposed to at least one preproduction or production well within 1 km, 115,648 (10.9%) were within 3 km, and 239,764 (22.7%) were within 10 km. For monitor-days with data for $PM_{2.5}$ and VOCs, there were no preproduction wells within 1 km.

Among exposed monitor-days, the median number of preproduction wells within each upwind 1-km bin was between 1 and 4, with a maximum of 41 (Table S2). For producing wells, median upwind exposure spanned 7.2 to 166.9 BOE, with a right-skew and a maximum of 24,166.1 BOE. There was both seasonal and geographic variation in wind direction: in the San Joaquin Valley, the wind predominantly originated in the northwest; in the South Coast basin, wind predominantly came from the southwest (Fig. S1). Exposure to preproduction wells was correlated with exposure to production volume for all annuli beyond 1 km. Across producing wells, daily production volume was right-skewed, with a median of 7.3 BOE per day and mean ($\pm$ SD) of 17.1 ($\pm$ 50.6) BOE per day. Exposure to preproduction wells was highly correlated for adjacent annuli and moderately correlated with further annuli; we observed a similar trend for production volume (Table S3). Exposure to preproduction wells was moderately correlated with exposure to production volume at distances greater than 1 km from wells.

3.2. Primary analyses

In the primary analysis, we observed increased concentrations of $PM_{2.5}$, CO, NO_2, and O_3 with proximity to preproduction wells (Fig. 3). For $PM_{2.5}$, we observed an increase of 2.35 μg m^{-3} (95% CI: 0.81, 3.89) for each additional upwind preproduction well site within 2 km of the monitor, and 0.97 μg m^{-3} (0.52, 1.41) for an additional well between 2 and 3 km from the monitor. For CO, we observed an increase of 0.09 ppm (-0.0004, 0.18) with an additional upwind well within 2 km and 0.02 (0.004, 0.032) for a well at 2-3 km. Concentrations of NO_2 increased 2.27 with well at 0-1 km, 2.91 (0.99, 4.84) for a well at 1-2 km, and 0.65 (0.31, 0.99) for a well at 2-3 km upwind. For O_3, there

Table 1
Descriptive statistics of the air monitors, pollutant concentrations, and meteorological factors during the study period, 2006-2019. The unit of observation is the monitor-day; some monitors observe multiple pollutants. VOCs in the dataset comprise non-methane volatile organic compounds.

	≤ 10 km to wells	> 10 km to wells	All
Monitors, *n* (column %)	79 (25.2)	235 (74.8)	314 (100)
Urban	57 (72.2)	151 (64.3)	208 (66.2)
Rural	22 (27.8)	84 (35.7)	106 (33.8)
Sacramento Valley	16 (20.2)	26 (11.1)	42 (26.6)
San Joaquin Valley	18 (22.8)	24 (10.2)	42 (26.6)
South Central Coast	15 (19.0)	14 (6.0)	29 (18.4)
South Coast	15 (19.0)	30 (12.8)	45 (28.5)
$PM_{2.5}$	43 (54.4)	155 (66.0)	198 (63.1)
CO	34 (43.0)	76 (32.3)	110 (35.0)
NO_2	45 (57.0)	94 (40.0)	139 (44.3)
O_3	65 (82.3)	172 (73.2)	237 (75.5)
VOCs	24 (30.4)	24 (10.2)	48 (15.3)
Observations, *n* (column %)	307,095 (29.0)	751,135 (71.0)	1,058,230 (100)
Urban	214,011 (69.7)	507,287 (67.5)	721,298 (68.2)
Rural	93,084 (30.3)	243,848 (32.5)	336,932 (31.8)
$PM_{2.5}$	137,657 (44.8)	317,065 (42.2)	454,722 (43.0)
CO	98,165 (32.0)	229,646 (30.6)	327,811 (31.0)
NO_2	157,567 (51.3)	297,197 (39.6)	454,764 (43.0)
O_3	252,572 (82.2)	588,448 (78.3)	841,020 (79.5)
VOCs[a]	44,992 (14.7)	49,357 (6.6)	94,349 (8.9)
2006–2009	77,013 (25.1)	200,404 (26.7)	277,417 (26.2)
2010–2014	104,839 (34.1)	264,066 (35.2)	368,905 (34.9)
2015–2019	107,248 (34.9)	268,876 (35.8)	376,124 (35.5)
Smoke plume overhead	21,780 (7.1)	54,299 (7.2)	76,079 (7.2)
Pollutant concentrations, daily mean ± SD			
$PM_{2.5}$ (μg/m^3)	10.6 ± 9.5	9.9 ± 9.0	10.1 ± 9.1
CO (ppm)	0.5 ± 0.4	0.5 ± 0.4	0.5 ± 0.4
NO_2 (ppb)	21.4 ± 14.6	22.1 ± 14.5	21.9 ± 14.5
O_3 (ppm)	0.04 ± 0.01	0.04 ± 0.02	0.04 ± 0.02
VOCs (ppb C)	120 ± 166	104 ± 142	112 ± 155
Meteorological factors, daily mean ± SD			
Precipitation (mm)	0.9 ± 4.0	1.2 ± 5.1	1.1 ± 4.8
Temperature (°C)	18.6 ± 7.8	17.2 ± 9.1	17.6 ± 8.8
Wind speed (m/s)	3.0 ± 2.1	3.2 ± 2.0	3.1 ± 2.0

[a] The data for VOCs includes observations for 1999-2019.

were no significant changes for an additional well within 2 km, an increase of 0.31. (0.20, 0.42) with an additional well at 2-3 km, and an increase of 0.14 (0.05, 0.23) with a well at 3-4 km. There were no increases in concentration with upwind exposure to VOCs, though notably there was no exposure to preproduction wells within 1 km. Across all pollutants, we did not observe any substantial increased concentrations beyond 4 km. In the placebo test, with exposure assessed to downwind wells, we did not observe any substantial increases in pollutant concentrations.

We observed increased concentrations of $PM_{2.5}$, NO_2, O_3, and VOCs with higher exposure to upwind production (Fig. 4). We estimated the marginal effect of exposure to an additional 100 BOE of daily total oil and gas volume within each 1-km annulus. This degree of exposure roughly corresponds with median upwind production volume within each annulus among exposed monitor-days (Table S2) and is comparable to cutoffs used in recent population health work (Tran et al., 2020). For each additional 100 BOE of total oil and gas production within 1 km, we observed an increase of 1.93 μg m^{-3} (95% CI: 1.08, 2.78) in the concentration of $PM_{2.5}$. For NO_2, we observed an increase of 0.62 ppb (0.37, 0.86) with an additional 100 BOE within 1 km. The concentration of O_3, increased by 0.11 ppb (0.08, 0.14) with for each 100 additional BOE at 1-2 km. There was an increase in VOC concentrations of 0.04 (0.01, 0.07) ppb C for an additional 100 BOE of production within 1 km. We did not observe any substantial changes in CO concentrations with upwind exposure to production volume. In the downwind placebo tests, we observed an increase in $PM_{2.5}$ concentrations for exposure to increased production within 1 km, a small increase in NO_2 concentrations at 1-2 km, and an increase in O_3 at 3-4 km.

3.3. Sensitivity analyses

We performed several sensitivity analyses. Fitting models that included exposure variables for both preproduction and production did not substantially change the results; point estimates and confidence intervals were similar in models with exposure variables for both preproduction and production compared to models examining each exposure separately (Fig. S4). In models with polynomial term for exposure we did not see evidence of non-linear responses to upwind exposure. Changing model specification in the primary analysis for preproduction wells (Table S4) or for production volume did not qualitatively change findings (Table S5). In a sensitivity analysis, we fit the model as described above but omitted the 35,422 monitor-days with smoke plumes overhead, comprising 7.8% of the $PM_{2.5}$ analytic dataset. The results were similar to the smoke-adjusted results for exposure to wells in both the preproduction and production stages (Fig. S3).

4. Discussion

We observed higher concentrations of ambient air pollutants at air monitors exposed to wells in both the preproduction and production stages. Concentrations of $PM_{2.5}$ were substantially higher on days when a well was in preproduction within 3 km of the monitor, and also when production volume increased within 1 km of the monitor. Notably, we observed increases in $PM_{2.5}$ within 1 km of producing wells with and without considering wind direction. There are several possible explanations for this result: it may be attributable to high volume of producing wells near monitors in San Joaquin Valley orthogonal to the upwind direction, imperfect data on wind direction,

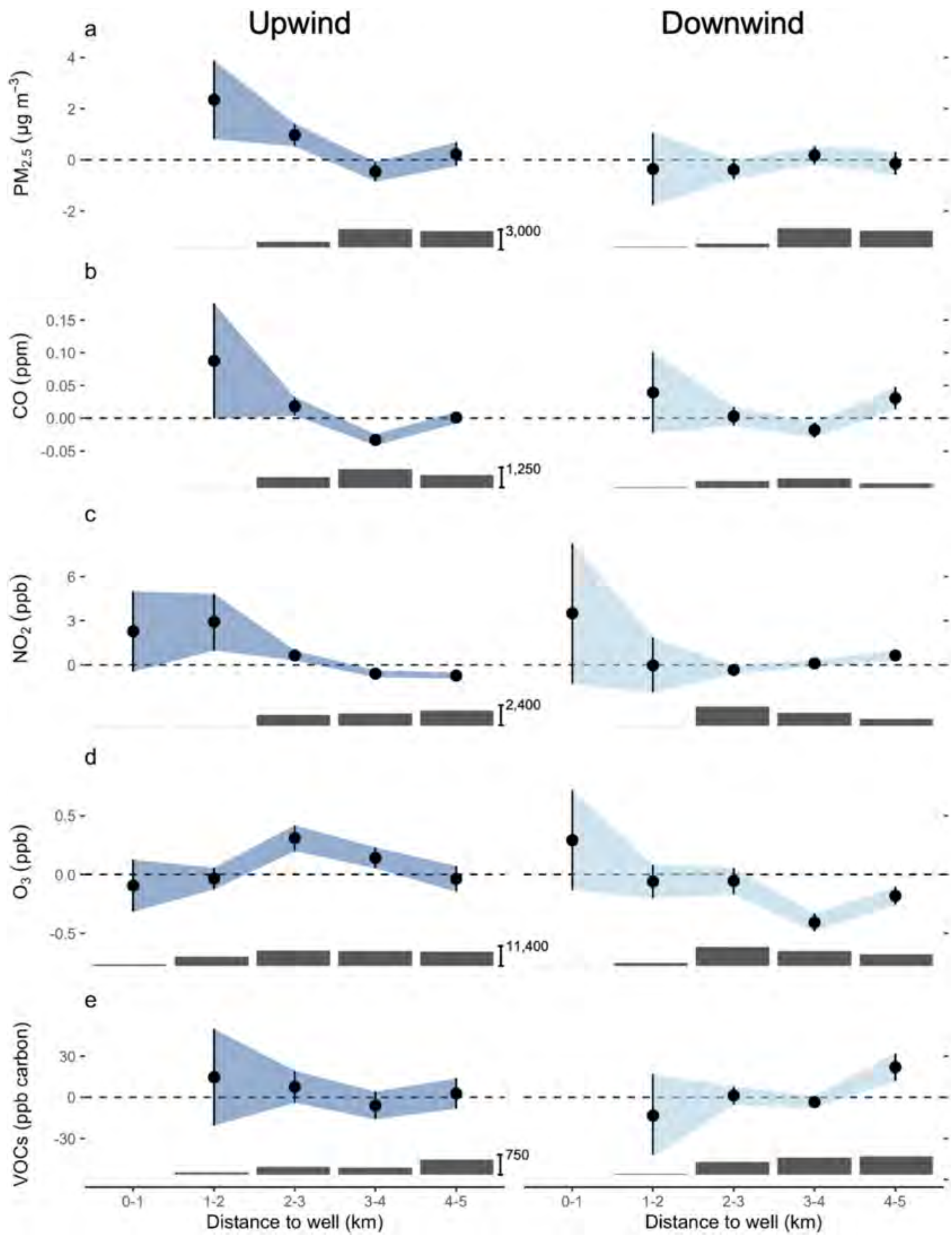

Fig. 3. Point estimates (95% CIs) for the marginal effect of one additional preproduction well upwind (left column) and downwind (right column) of the monitor. The bar plots show the number of monitor-days with exposure at least one preproduction well within each distance bin.

or shifts in wind direction during the day that were not adequately captured when we integrated wind direction over the course of a 24 h period. In addition to elevated $PM_{2.5}$ levels, concentrations of O_3 increased when production activity increased between 1 and 4 km upwind of the monitor, but not for activity within 1 km of the monitor. This result may be attributable to secondary formation from primary pollutants emitted from during preproduction and production. Ground-level O_3 may be secondarily formed from photochemical reactions involving CO, NO_x, and VOCs, all of which we also observed were emitted from wells (Real et al., 2007; Rodriguez et al., 2009). We observed increased CO concentrations on days when preproduction wells were drilled within 3 km of the monitor. Concentrations of NO_2 were higher on days when there was a preproduction well within 2 km or increased production volume within 1 km. For VOCs, we found higher concentrations when production volume increased within 1 km of the monitor. In the current study, VOCs comprised non-methane organic compounds including acetaldehyde, benzene, ethylene, and formaldehyde.

In models that considered both preproduction wells and production volume, we observed similar estimates to the models where we considered preproduction and production separately, as shown in Fig. S4. Preproduction activity near monitors was correlated with production volume, though this may not be apparent based on the correlation matrix in Table S3, which shows low correlation between preproduction

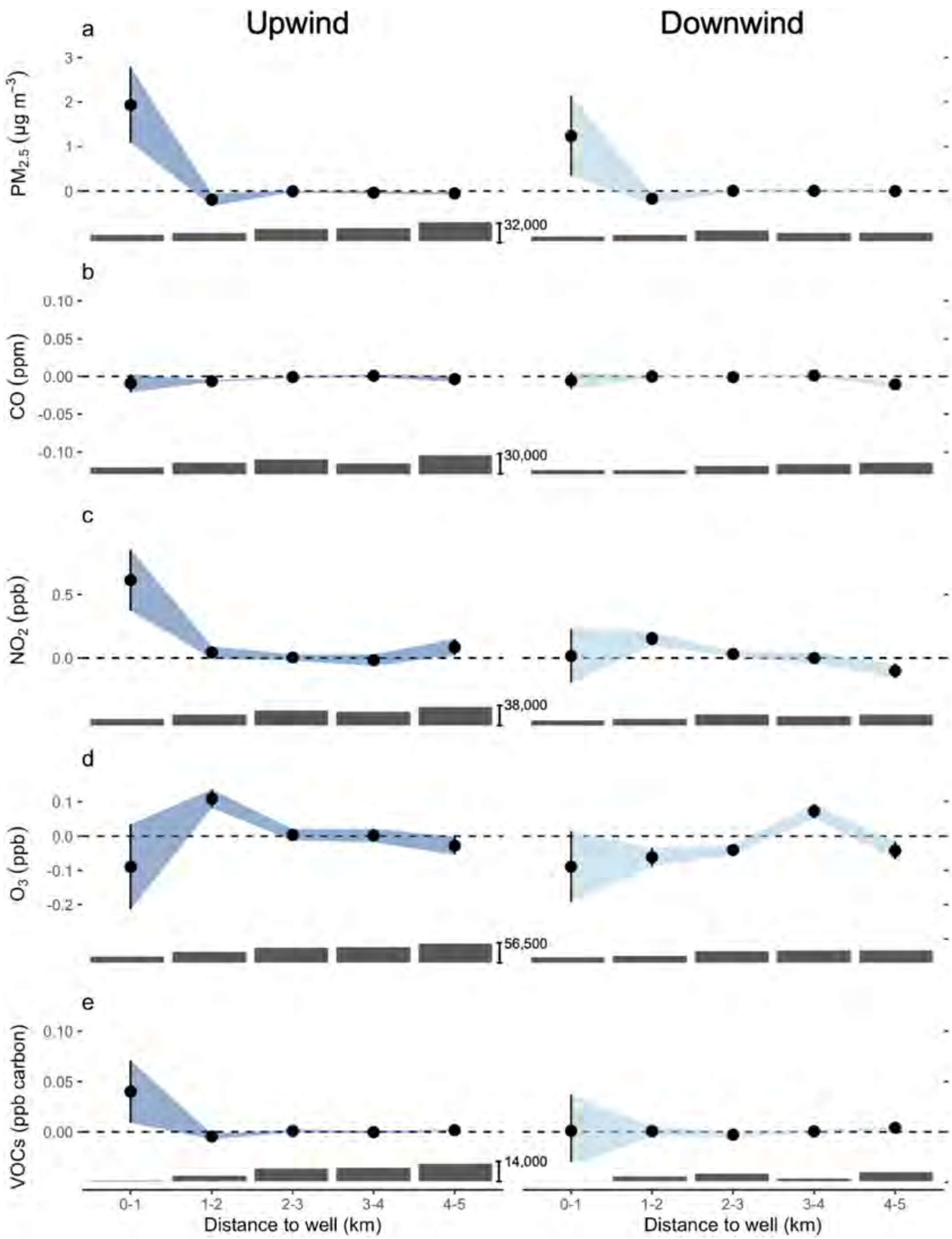

Fig. 4. Point estimates (95% CIs) for the marginal effect of 100 additional barrels of oil equivalent (BOE) of daily production volume, for wells upwind (left column) and downwind (right column) of the monitor. The bar plots show the number of monitor-days with exposure at least 1 BOE of daily production volume within each distance bin. Note that more monitor-days had exposure to production volume than preproduction wells.

wells and production volume. However, among all monitor-days with a preproduction well within 1 km of the monitor, there was also >0 BOE of production volume.

In this study, we conducted a quasi-experimental analysis that relied on the existing network of air quality monitors. The siting of air quality monitors is delegated to local authorities and prior studies have found evidence of bias in where monitors are sited, which should be considered when interpreting the results from the current study (Grainger et al., 2017; Grainger and Schreiber, 2019). For example, in counties just marginally in attainment for National Ambient Air Quality Standards (NAAQS), regulators had an incentive to place new monitors far from pollution sources, whereas in areas already in non-attainment, the regulators were incentivized to place monitors close to polluting sources (Grainger et al., 2017). This could lead to biased estimates of emissions from oil and gas wells, as monitors may be sited away from the most intensively producing oil fields. There is also evidence that monitors are less likely to be located in communities with racially and socioeconomically marginalized populations, which could lead to underestimation of oil and gas-related emissions if oil production in excluded areas was more intensive and polluting (Grainger and Schreiber, 2019). In the current study, the majority of oil and gas production was concentrated in Kern and Los Angeles Counties, both of which were in non-attainment for $PM_{2.5}$ throughout the study period (Environmental Protection Agency, 2021).

Findings from the current study indicate both primary emission and secondary formation of pollutants from upstream oil and gas production activities. However, identifying specific processes that resulted in observed pollutant emissions was outside the scope of the study.

4.1. Comparison to prior studies

Using proximity as a metric of exposure to upstream oil and gas production appears to adequately capture exposures to chemical contaminants. Proximity-based methods, such as inverse distance weighting or estimating production activity within 1 km of receptors, have been used in prior population health studies to estimate acute or chronic exposure to wells. The five pollutants we examined in this study represent a subset of potential hazards associated with exposure to oil and gas wells, which may include other air pollutants as well as water and noise pollution (Adgate et al., 2014; Jackson et al., 2014). Recent studies from California have reported fugitive methane from idle and unplugged wells, as well as urban oil and gas infrastructure, which may correlate with emissions of benzene, toluene, ethylene, xylene, and other air toxics (Lebel et al., 2020; Okorn et al., 2021). To differentiate risks conferred by air pollutants, population health researchers could utilize variations in wind direction.

Prior field studies have also found emissions of pollutants from upstream oil and gas facilities. A 2018 study in Texas found high concentrations of nitrous oxides and saturated hydrocarbons associated with oil and gas production in the Eagle Ford Shale (Schade and Roest, 2018). Another recent study in Colorado, which combined in situ monitoring and cancer risk assessment, found higher exposure to benzene and other non-methane hydrocarbons (toluene, ethylbenzene, and xylene) and elevated risk of cancer and other adverse health outcomes with close proximity to oil and gas facilities (McKenzie et al., 2018). Notably, the dataset in the current study did not include toluene, ethylbenzene, and xylene. Garcia-Gonzales et al. (2019a) found higher concentrations of VOCs downwind of a well site in Los Angeles. A study in Pennsylvania found that exposure metrics used in prior epidemiological studies were poorly correlated with observed pollutant concentrations (Wendt Hess et al., 2019). However, this study assessed exposure to wells at distances greater than 10 km, where we would not expect to detect increases in pollution, and the authors did not account for meteorological factors that may affect pollutant concentrations (Buonocore et al., 2020).

In prior studies, Tran et al. (2020) and Gonzalez et al. (2020) used differing proximity metrics to assess exposure to upstream oil and gas production and adverse birth outcomes in California. For their analysis of production volume and adverse birth outcomes, Tran et al. used a similar exposure assessment method to the one we employed in the current study, assessing “high” exposure to births with >100 BOE within 1 km of the residence. In the current analysis, we modeled exposure to production volume continuously rather than categorically. We found substantial increases in concentrations of $PM_{2.5}$, NO_2, and O_3 with exposure to an additional 100 BOE within 1 km, indicating that the metrics employed by Tran et al. likely were effective in capturing aspects of air pollution near active wells. Gonzalez et al. used inverse distance-squared weighting (IDW), a different approach that relies on the assumption that both density and proximity of wells confers risk of air pollution exposures. Notably, Gonzalez et al. (2020) conducted an exploratory analysis of the association between proximity to oil and gas wells, assessed using an IDW index, and concentrations of four pollutants (NO_2, O_3, PM_{10}, and $PM_{2.5}$). For that supplemental analysis, Gonzalez et al. also used data from EPA Air Quality System for mean monthly concentrations of air pollutants and fit fixed effects linear regression models estimating the effect of “high” exposure to wells (the highest tertile of the IDW index). These authors observed substantially higher concentrations of PM_{10} and $PM_{2.5}$, lower concentrations of NO_2, and no substantial changes for O_3; for all pollutants, effects. This indicates that the IDW method may be less effective as an exposure metric for the air pollutants investigated in this study than the methods employed in the current study. Additionally, the approaches in both Tran et al. (2020) and Gonzalez et al. (2020) may not adequately capture exposure to secondary pollutants such as O_3, which in the current study had higher concentrations several km downwind of wells.

4.2. Limitations and strengths

The current study had several limitations. We relied on daily changes in wind direction as a source of exogenous variation. On days with variable wind direction, estimating mean wind direction integrated over the course of the day could lead to exposure misclassification if, for example, wind blew from multiple directions during the course of a 24-h period. Data for many pollutants that may be emitted during upstream oil and gas production operations are not routinely monitored and reported in the EPA Air Quality System. Consequently, the results of the current study likely reflect only a subset of pollutants potentially emitted from upstream oil and gas production. Population health studies referring to our estimates of chemical contaminant exposure should consider the possibility of co-exposures to additional pollutants emitted during oil and gas production. We also did not have sufficient data to investigate specific VOC constituents, which may be associated with particular health endpoints of interest. Additionally, there were relatively few monitor-days with exposure to preproduction wells within 1 km. None of the monitors that measure concentrations of $PM_{2.5}$ and VOCs were within 1 km of a preproduction well. We found evidence that drilling sites up within 1 to 3 km of air monitors increased $PM_{2.5}$ concentrations, and concentrations of $PM_{2.5}$ within 1 km of preproduction wells may be similar to or higher than our estimates for wells at 1-3 km. We did not expect to observe changes in VOC concentrations further than 1 km, as prior work has reported decay of VOCs within 100-200 m from well sites (Garcia-Gonzales et al., 2019a; Zielinska et al., 2014). Because of this, we were unable to make any inferences about the effect of preproduction activities on concentrations of VOCs.

In the primary analyses, we adjusted for exposure to wildfire smoke plumes to account for potential contributions of smoke to the pollutants of interest. Exposure was assessed as the number of overhead plumes for each monitor-day, but this method may not accurately indicate smoke conditions at ground level. A sensitivity analysis for $PM_{2.5}$ omitting smoke days from the analysis yielded similar results to the smoke-adjusted models, suggesting that our statistical adjustment for smoke plumes was sufficient.

For the analyses of wells in the production stage, data on total oil and gas production volume were available at the monthly level. Because of this constraint, in the exposure assessment we assumed that production occurred evenly throughout the month. This could lead to exposure misclassification if production was concentrated in certain days of the month. Future researchers building on these findings should consider obtaining daily production volume data, if possible. Finally, we were not able to differentiate between drilling or production methods (i.e., conventional vs. unconventional methods, such as hydraulic fracturing), so we were not able to determine whether certain unconventional methods resulted in higher emissions.

Strengths of this study include the large panel dataset, comprising over 1 million daily observations from high quality air monitors with broad geographic and temporal variation. We were able to control for unobserved potential confounders through the study design, using wind as a plausibly exogenous source of variation uncorrelated to both upstream oil production and other sources of pollution. The monitor fixed effect accounts for average differences between monitoring locations, such as from pollution sources unrelated to oil and gas. Leveraging temporal variation from oil production activities and daily changes in wind direction accounts for other nearby pollution sources that are not both spatially collocated and temporally correlated with oil and gas production. Based on this analytic approach, we think there is unlikely to be residual confounding. Additionally, we conducted several tests to validate the robustness of the results.

5. Conclusion

We conducted a quasi-experimental study to examine whether upstream oil and gas production results in emissions of ambient air pollutants. Adjusting for geographic, meteorological, seasonal, and time-trending factors, and leveraging daily changes in wind direction as an exogenous source of variation, we observed that proximity to oil and gas wells in both preproduction and production increased concentrations of $PM_{2.5}$, CO, NO_2, O_3, and VOCs at distances up to 4 km downwind of wells. These findings indicate that proximity to wells is an appropriate metric for air pollution-related exposures in population health studies. Notably, increases in $PM_{2.5}$ concentrations near wells could be a mediating factor for previously reported increases in risk of adverse birth outcomes with proximity to wells in California (Bekkar et al., 2020; Gonzalez et al., 2020; Tran et al., 2020). Further research on hazards associated with upstream oil and gas production would improve understanding of potential health and environmental risks. Acute emissions of particular pollutants may be associated with specific steps of oil and gas preproduction or production, and more work is needed to determine if this is the case and, if so, which processes produce high emissions. Mitigating exposure to oil and gas wells would likely reduce exposure to ambient air pollutants.

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CRediT authorship contribution statement

David J.X. Gonzalez: Conceptualization, Data curation, Methodology, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Christina K. Francis:** Data curation, Writing – original draft. **Gary M. Shaw:** Writing – review & editing. **Mark R. Cullen:** Methodology, Writing – review & editing. **Michael Baiocchi:** Methodology, Writing – review & editing. **Marshall Burke:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Data availability

Data and code used in this analysis are available at https://github.com/djxgonzalez/cal-drilling-air-quality.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.150298.

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Exhibit 6 of 13 - Healthcare Professionals 2019. Oil and Gas Extraction LA and Public Health Evidence

October 11, 2019

Eric Garcetti, Mayor of Los Angeles
Los Angeles City Council
200 N. Spring Street
Los Angeles, CA 90012

RE: Oil and Gas Extraction in Los Angeles and Public Health Evidence

As scientists and health professionals with expertise in the impacts of oil and gas extraction on human populations or the environment, we are writing to ensure that the City of Los Angeles possesses analyses grounded in the most available, current and relevant epidemiological research as it considers policies to protect Los Angeles residents from environmental health risks with respect to oil and gas operations. **We have reviewed the analysis and recommendations of the City's recently-released report on oil and draw attention here to the existing evidence that demonstrates health impacts associated with upstream petroleum extraction among residents living ½ to 3 miles from drill sites. Current evidence suggests environmental and health risks further than the 600-ft recommendation proposed to be considered by the city. Many communities near oil extraction in Los Angeles are home to vulnerable populations, who may face cumulative environmental burdens.**

Recent reviews of scientific literature show growing evidence of adverse exposure and health impacts associated with petroleum extraction (Johnston, Lim, & Roh, 2018; Shonkoff, Hays, & Finkel, 2014). Los Angeles sits atop one of the largest urban oil fields in the country with over nearly 2500 active wells. A single drill site typically operates for decades and the extraction process produces emissions of multiple health-hazardous air pollutants, including benzene, toluene, ethylbenzene, xylene, formaldehyde, hydrogen sulfide, and methylene chloride. Many of these compounds are known to be toxic to human health, carcinogenic, cause respiratory harm, or are endocrine disrupting chemicals and can cause long-term developmental or reproductive harm—a consideration for health across generations (Zielinska, Campbell, & Samburova, 2014; Moore, Zielinska, Pétron, & Jackson, 2014; Field, Soltis, & Murphy, 2014; Colborn, Schultz, Herrick, & Kwiatkowski, 2013). These chemicals can migrate off-site due to fugitive emissions, spills, leaks, or accidents.

Despite relatively few studies having been conducted in Los Angeles, the current body of knowledge drawing from scientific studies on upstream oil and gas extraction from across diverse areas of the US and globally, indicate a substantive base of evidence to inform public health efforts by the City of Los Angeles. For example, despite diversity in extraction techniques, geology and local populations, scientific studies have consistently identified drilling activities significantly associated with adverse birth outcomes in Pennsylvania (Casey et al., 2015; Hill, 2012; Stacy et al., 2015), Colorado (McKenzie et al., 2014; McKenzie, Allshouse, & Daniels, 2019), Texas (Whitworth, Marshall, & Symanski, 2017; Walker Whitworth, Kaye Marshall, & Symanski, 2018) and Oklahoma (Janitz, Dao, Campbell, Stoner, & Peck, 2019). *While the exposure measurements in these studies vary based on the community, such* *adverse perinatal effects are associated with maternal proximity of ½ mile to 3 miles from drill activity.*

Recent health surveys near petroleum extraction sites have reported symptoms of throat and nasal irritation, eye burning, sinus problems, headaches, skin problems, severe fatigue, loss of smell, cough, nosebleeds and psychological stress (Steinzor, Subra, & Sumi, 2013; Rabinowitz et al., 2015) (Elliott et al., 2018) (Jemielita et al., 2015) (Casey, Wilcox, Hirsch, Pollak, & Schwartz, 2018). Among adults, risk factors for cardiovascular disease increases with the intensity of oil and gas activity nearby (L. M. McKenzie et al., 2019). These symptoms were more common in individuals living near oil and gas facilities compared to those farther away. Others identify neurological symptoms, kidney damage and thyroid problems among residents living in oil extraction regions when compared to those living farther away. Stress, including social and economic stress, can make these health conditions worse (Morello-Frosch, Zuk, Jerrett, Shamasunder, & Kyle, 2011)

Additional studies demonstrate a higher burden of cancer mortality in communities exposed to oil extraction (San Sebastián M, Armstrong B, A, & C., 2001) (Moolgavkar, Chang, Watson, & Lau, 2014) (L. M. McKenzie et al., 2017) (Finkel, 2016). For example, in Colorado, scientists found that children diagnosed with leukemia had a 4.6 increased odds of living in an area with dense petroleum extraction (L. M. McKenzie et al., 2017).

Air surrounding oil and gas production areas is particularly vulnerable to toxic emissions. With relevance to drilling operations in California, a recent review concluded that the production phase, with the lengthy operation timeframes, episodic peak emission events, and largest number of hazardous air pollutants sourced to the various equipment and operations, has the potential to emit the highest concentrations of hazardous air pollutants over the longest time period (Garcia-Gonzales, Shonkoff, Hays, & Jerrett, 2019). Air quality is further compromised by truck traffic to and from the drilling site or operation of diesel equipment (Goodman et al., 2016) (Allshouse, McKenzie, Barton, Brindley, & Adgate, 2019) (Blair, Brindley, Dinkeloo, McKenzie, & Adgate, 2018). Exposure to these air pollutants have been shown to be higher in areas near drilling sites (Lisa M. McKenzie, Witter, Newman, & Adgate, 2012) (Colborn et al., 2013) (Pétron et al., 2012) (Macey et al., 2014) – including in Los Angeles (Collier-Oxandale et al., 2018; Shamasunder et al., 2018). The scientific literature demonstrates adverse human health impacts from exposure to these chemicals (Lisa M. McKenzie et al., 2012) (Atsdr, 1999). Recent literature identifies noise as an important co-exposure near operations (Richburg & Slagley, 2019) (Radtke, Autenrieth, Lipsey, & Brazile, 2017). Acute inhalation exposures to petroleum hydrocarbons have found increased risks of eye irritation and migraine headaches (Kim et al., 2009) (Tunsaringkarn, Ketkaew, Siriwong, & Rungsiyothin, 2013) (Tustin et al., 2017), as well as asthma symptoms (Rasmussen et al., 2016) (White et al., 2009) (Wichmann et al., 2009).

Studies of animals living in oil producing regions have shown an increased accumulation of toxins in various organs, in particular toxic metals as well as damage to the kidney (Miedico et al., 2016) (Al-Hashem, 2011). Toxic metals and petroleum hydrocarbons have also been measured in soil and water near oil extraction sites (Johnston et al., 2018), including diverse locations such as Texas (Bojes & Pope, 2007,) China (Zhang et al., 2013) (Fu, Cui, & Zang, 2014) (Wang, Cao, Liao, Huang, & Tang, 2015), Nigeria (Asia, Jegede, Jegede, Ize-Iyamu, & Akpasubi, 2007) and Iraq (Alawi & Azeez, 2016).

Hydrogen sulfide (H_2S) is an odorant gas associated with oil drilling. Most human organ systems are susceptible to the toxic effects of H_2S, particularly mucus membranes, including the central nervous system, the respiratory system, the cardiovascular system and the gastrointestinal system (Reiffenstein, Hulbert, & Roth, 1992). At ambient levels, odorant chemicals may produce irritation of the eyes, nose, and throat. Such compounds can induce symptoms such as nausea, vomiting, headaches, stress, negative mood, and a stinging sensation (Schiffman, Miller, Suggs, & Graham, 1995) (Wing et al., 2008). Odors that are viewed as unpleasant, embarrassing, or sickening may interfere with mood, beneficial uses of property, and social activities. There is evidence that chronic exposure to elevated ambient concentrations contribute to harm to the respiratory system in both adults and children in addition to elevated cough, headaches and wheezing (Jaakkola, Paunio, Virtanen, & Heinonen, 1991) (Marttila, Jaakkola, Vilkka, Jappinen, & Haahtela, 1994).

Buffers or setbacks have been shown to be a meaningful public health policy approach to limit human health exposures to harmful contaminants (Fry, 2013) (Haley, McCawley, Epstein, Arrington, & Bjerke, 2016) (Lisa M McKenzie, Allshouse, Burke, Blair, & Adgate, 2016) (Banan & Gernand, 2018). From a public health perspective, given the existing evidence on adverse health risks from oil and gas development, it is important to reduce exposures to harmful pollutants at home, in schools and at work places.

Sincerely,

Jill Johnson, PhD, *Assistant Professor of Preventive Medicine, University of Southern California*

Bhavna Shamasunder, PhD, MES, *Associate Professor, Urban and Environmental Policy, Occidental College*

Ed Avol, MD., *Professor of Clinical Medicine and Chief, Environmental Health Division, Department of Preventive Medicine, University of Southern California*

Joan Casey, PhD, *Assistant Professor, Environmental Health Sciences, Mailman School of Public Health, Columbia University*

Lara Cushing, PhD, MPH, *Assistant Professor, San Francisco State University*

Shohreh Farzan, PhD, *Assistant Professor of Preventive Medicine, University of Southern California*

Meredith Franklin, PhD, *Associate Professor of Preventive Medicine, University of Southern California*

Erika Garcia, PhD, MPH, *Postdoctoral Scholar, Department of Preventive Medicine, University of Southern California*

Jimmy Hara, MD, *Clinical Professor of Family Medicine at the David Geffen School of Medicine at UCLA, Residency Director Emeritus for the Kaiser Permanente Los Angeles Family Medicine*

Megan Herting, PhD, *Assistant Professor of Preventive Medicine, University Southern California*

Martha Matsuoka, PhD, MCP, *Associate Professor, Urban & Environmental Policy and Executive Director, Urban & Environmental Policy Institute, Occidental College*

Rachel Morello-Frosch, PhD, MPH, *Professor, School of Public Health and Department of Environmental Science, Policy and Management, University of California, Berkeley*

Jyoti Puvuula, MD, *Harbor-UCLA Department of Family Medicine & Doctors for Global Health*

Linda Rudolph, MD, MPH, *Senior Advisory, Public Health Institute*

James Sadd, PhD, *Professor of Environmental Science, Occidental College*

Ted Schettler MD, MPH, *Science Director, Science and Environmental Health Network*

(Affiliations for identification purposes only)

CC:
Mike Feuer, Los Angeles City Attorney
Uduak-Joe Ntuk, Los Angeles Petroleum Administrator

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Exhibit 7 of 13 - Johnston 2021. Respiratory health, pulmonary function and local engagement in urban communities near oil development

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Respiratory health, pulmonary function and local engagement in urban communities near oil development

Jill E. Johnston [a,*], Temuulen Enebish [a], Sandrah P. Eckel [a], Sandy Navarro [b], Bhavna Shamasunder [c]

[a] Department of Preventive Medicine, Keck School of Medicine, University of Southern California, Los Angeles, CA, USA
[b] L.A. Grit Media, Los Angeles, CA, USA
[c] Department of Urban & Environmental Policy, Occidental College, Los Angeles, CA, USA

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ABSTRACT

Background: Modern oil development frequently occurs in close proximity to human populations. Los Angeles, California is home to the largest urban oil field in the country with thousands of active oil and gas wells in very close proximity to homes, schools and parks, yet few studies have investigated potential health impacts. The neighborhoods along the Las Cienagas oil fields are situated in South LA, densely populated by predominantly low-income Black and Latinx families, many of whom are primarily Spanish-speakers.
Methods: A cross-sectional community-based study was conducted between January 2017 and August 2019 among residents living <1000 m from two oil wells (one active, one idle) in the Las Cienagas oil field. We collected self-reported acute health symptoms and measured FEV1 (forced expiratory volume in the first second of exhalation) and FVC (forced vital capacity). We related lung function measures to distance and direction from an oil and gas development site using generalized linear models adjusted for covariates.
Results: A total of 961 residents from two neighborhoods participated, the majority of whom identify as Latinx. Participants near active oil development reported significantly higher prevalence of wheezing, eye and nose irritation, sore throat and dizziness in the past 2 weeks. Among 747 valid spirometry tests, we observe that living near (less than 200 m) of oil operations was associated with, on average, −112 mL lower FEV1 (95% CI: −213, −10) and −128 mL lower FVC (95% CI: −252, −5) compared to residents living more than 200 m from the sites after adjustments for covariates, including age, sex, height, proximity to freeway, asthma status and smoking status. When accounting for predominant wind direction and proximity, we observe that residents living downwind and less than 200 m from oil operations have, on average, −414 mL lower FEV1 (95% CI: −636, −191) and −400 mL lower FVC (95% CI: −652, −147) compared to residents living upwind and more than 200 m from the wells.
Conclusions: Living nearby and downwind of urban oil and gas development sites is associated with lower lung function among residents, which may contribute to environmental health disparities.

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1. Introduction

Modern oil development frequently occurs in close proximity to human populations. Globally, there are approximately 40,000 oil fields (Mead, 1993) that have the potential to effect over 600 million people living nearby (O'Callaghan-Gordo et al., 2016). Over the past decade, oil production in the United States (US) has nearly doubled while natural gas production rose 50% reversing a longstanding decline in production (Energy Information Administration, 2018). An estimated 8.6 million

* Corresponding author.
E-mail address: jillj@usc.edu (J.E. Johnston).

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people live less than 1600 m from an active oil extraction site in the US. (Czolowski et al., 2017) California (CA), together with Texas, North Dakota, and Alaska account for ~60% of all oil produced domestically. Public health concern has accompanied this rapid growth in oil production (Cotton and Charnley-Parry, 2018).

As oil and gas development is becoming more common near where people live, work and play, there is an increasing potential for human exposure to contaminants associated with drilling and fossil fuel extraction (Adgate et al., 2014; Finkel et al., 2013). Recent research demonstrates multiple health-hazardous air pollutants associated with petroleum extraction, including particulate matter (PM), nitric oxides (NOx), polyaromatic hydrocarbons, benzene, naphthalene, xylenes, toluene, ethylbenzene, formaldehyde, and sulfuric acid (Field et al., 2014). Documented health effects from exposure to such chemicals include symptomatic acute physical and respiratory effects, dizziness, headaches, and fatigue along with respiratory system irritation, such as difficulty breathing and impaired lung function (ATSDR., 1999; Bolden et al., 2015).

While there are few epidemiological studies related to upstream oil extraction, results from three recent health surveys near natural gas extraction and hydraulic fracturing sites reported symptoms of throat and nasal irritation, eye burning, sinus problems, headaches, skin problems, loss of smell, cough, nosebleeds and stress (Steinzor et al., 2013; Rabinowitz et al., 2015; Ferrar et al., 2013). These symptoms were more common in individuals living nearby gas facilities compared to those farther away. Elevated incidence of pediatric asthma hospitalization has been observed among nonurban areas with the highest levels of gas drilling activity (Willis et al., 2018, 2020; Rasmussen et al., 2016). Survey-based studies documented higher rates of headaches, dizziness, and eyes, nose, throat and skin irritation among residents near oil development compared to people living farther away (San Sebastián et al., 2001; Kponee et al., 2015). Recent studies in CA and Texas identified adverse birth outcomes associated with oil extraction activities(Cushing et al., 2020; Gonzalez et al., 2020; Tran et al., 2020).

Los Angeles (LA) County, CA, is home to one of the most petroleum-dense basins in the world, with thousands of oil and gas extraction wells spread across multiple oil fields in 70 different communities (Fig. 1a) (Chilingar and Endres, 2005; Gamache and Frost, 2003). Approximately 1/3rd of the 10 million LA County residents live <1 mile of an active oil drilling site, and over 500,000 residents live <¼ mile (~400 m) (Sadd and Shamasunder, 2015). Some live as close as 60 feet from active oil operations (Fig. 1b) (Elkind, 2012). Such a dense, diverse population living in close proximity to oil is unmatched across the US (Elkind, 2012).

The neighborhoods atop the Las Cienagas oil fields are situated in South LA, populated by predominantly low-income Black and Latinx families. Over 90% of residents are people of color (self-identify as Latinx/Hispanic, Black, Asian and/or as a race other than White) and approximately three-quarters of households live below 200% of the federal poverty line (Shamasunder et al., 2018a). According to CalEnviroScreen, CA's environmental justice screening tool to identify highly vulnerable communities, this area is among the top 10% most disproportionately-environmentally burdened in the state (Office of Environmental H, 2017). These neighborhoods, when compared to the state, fall into the bottom 20% for educational attainment and among the top 15% for poverty based on CalEnviroScreen metrics. After an upswing in oil production in Las Cienagas oil field, nearby residents began to report adverse acute health symptoms, such as nosebleeds and headaches, ailments that have been described in other areas with oil and gas production (Lohah, 2014). Subsequently, one oil and gas development (OGD) site (which consists of multiple production wells) was shuttered by the city of Los Angeles, and is the "idle" site in this study as it was not actively producing oil or gas during the study period. Other sites, including the "active" study site, continued to extract oil from this field. We used community-driven methodology to assess respiratory health among community residents living in two neighborhoods in the Las Cienagas oil field which were within 1000 m of either active or idle OGD sites.

2. Methods

To examine the possible chronic deleterious effects of oil drilling operations in close proximity to neighborhoods in urban Los Angeles, we analyzed the relationship between OGD sites' proximity with self-reported acute symptoms and pulmonary function test results among diverse residents. A cross-sectional community-based study was conducted between January 2017 and August 2019 near two oil sites in the Las Cienagas oil field in South Los Angeles, CA. One OGD well site (in the North University Park neighborhood) housed 21 wells which were idle, that is, not actively producing any oil or gas, during the study period. The second OGD well site (in the Jefferson Park neighborhood) had 28 wells at the time of the study and was actively producing oil during the entire study period. The academic research team and Esperanza Community Housing collaborated to train *Promotores de Salud* (community health workers) in recruitment and research methods. A *Promotor de Salud* is a community member who is uniquely linked to the cultural and regional connections in the neighborhood and this local, networked approach offers an innovative model that provides culturally accessible

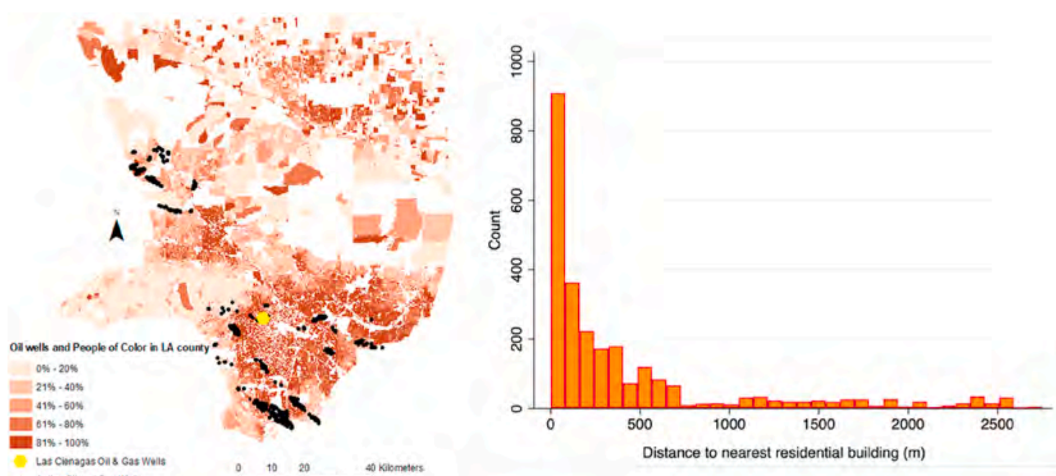

Fig. 1. a) Location of active oil wells and people of color (according to 2010 US Census block data) in Los Angeles County. Las Cienagas oil field is shown by the yellow dot. b) Proximity of active oil wells to residential homes in Los Angeles County (graph on right). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

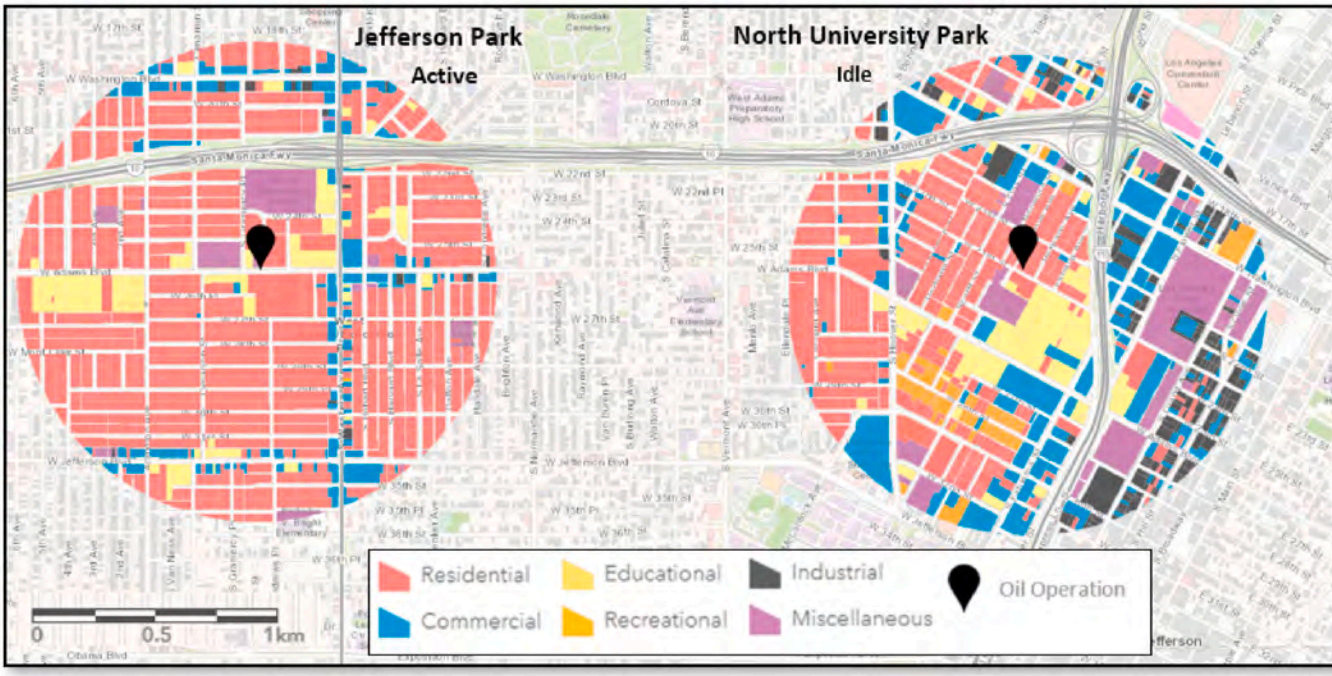

Fig. 2. Oil operation locations and land-use around the two neighborhoods in South Los Angeles, California.

health education for low-income communities of color and supports changes for improved health (Rhodes et al., 2007; Dominguez et al., 2015; Ingram et al., 2014; Pérez and Martinez, 2008). We partnered with skilled community *promotores* for recruitment in this neighborhood-based study. University of Southern California (USC) researchers and community partners went to local elementary schools, churches and door to door to distribute recruitment flyers, answer questions and invite residents to participate in the study. Flyers were posted in apartment buildings and distributed to school children when permission was granted. To be eligible, participants were at least 6 years old, spoke English, Spanish or Korean, and lived within 1000 m of one of the OGD sites of interest for at least two years. Multiple participants per household were eligible to participate if they met the inclusion criteria. Among the potential eligible participants that spoke to a community *promotor*, 74% agreed to participate in the study. Written informed consent was obtained from all participants 18 years of age or older, assent and parental consent were obtained from all participants younger than 18 years. All protocols, consent forms, and survey materials were approved by the University of Southern California Institutional Review Board. Participants who provided written consent completed a baseline demographic and health questionnaire, reported acute symptoms over the past two weeks, and provided physiological measurements.

2.1. Health questionnaire

If participants were under the age of 13, the parent/guardian completed the questionnaire. The questions were based on validated questionnaires from a Southern CA respiratory health study (Peters et al., 1999a) and adapted for accessibility and cultural relevance based on input from the *promotores* and Esperanza. The questionnaire was administered in the participant's preferred language (Spanish, English or Korean) and asked sociodemographic information, race/ethnicity, sex, age, tobacco exposure (e.g. smoking history, current smoking practices, presence of indoor environmental tobacco smoke), occupation and residential history. We collected information about disease history, including if the participant ever had a doctor-diagnosis of asthma. The participant was considered to have allergic rhinitis if answered affirmative to the question "Have you ever had hay fever?".

2.2. Acute symptoms survey

We asked questions regarding acute irritant and physical symptoms experienced during the previous two weeks, leveraging survey tools developed in partnerships with communities living near nuisance industries (Tajik et al., 2008; Schinasi et al., 2011). We considered the following acute symptoms: respiratory (wheezing or whistling of the chest, coughing every morning, sleep disturbed by wheezing, sore throat, chest tightness, or runny nose), mucous-membrane irritation (burning, tearing, or irritated eyes, burning or irritated nose), neurological (dizziness, headache, fatigue, ringing of the ears, seizure), gastrointestinal (nausea or vomiting, diarrhea), and as well as others (nosebleeds, backache, rash). Some symptoms that we considered to be unrelated to airborne OGD emissions (e.g. backache, vomiting, diarrhea, cold/flu) were included to address the possibility that residents might report excessive symptoms due to possible negative feelings about the well sites. These questions were collected on a scale with 4 categories within the past two weeks ("not at all", "once or twice", "a few times per week"or "daily"). We dichotomized the response into any symptom (Yes) or not at all (No) categories for interpretability and analysis purposes.

2.3. Lung function measurements

Lung function was assessed using a commercially available spirometer (ndd Easy-On PC, Andover MA) by trained study staff. Maximal-effort spirometry was overseen by trained personnel following American Thoracic Society criteria. Three to 7 blows were performed by each participant to establish consistency, representativeness, and performance credibility. Multiple variables were automatically collected and logged using the ndd software; FEV1 (forced expiratory volume in the first second of exhalation), FVC (forced vital capacity), and MMEF (maximal mid-expiratory flow). We focused on FEV1 and FVC as both measures are established as strong and independent predictors of respiratory disease, cardiovascular mortality and all-cause mortality (Baughman et al., 2012; Beaty et al., 1982; Mannino et al., 2003; Schünemann et al., 2000). Each participant's height (to nearest 0.1 cm) and weight (0.1 lbs) was also measured. Finally, each participant was asked if they had cold or flu symptoms within the past 72 h (defined as the presence of cough, fever, sore throat, and/or runny or stuffy nose).

2.4. Statistical analysis

We evaluated participant characteristics by neighborhood and variable distributions. We found the continuous spirometry data to approximate a normal distribution and proceeded with untransformed variables for subsequent analyses. Various representations of oil-well related exposures were then constructed. We assessed differences based on neighborhood (Model 1) and then distance from the oil well using a binary indicator of whether the participants' home was near (<200 m) versus farther (200–1000 m) from an oil well (Model 2). The selection of 200 m for the main analysis was chosen based on a changing relationship observed between distance and lung function among study participants (Figure S1). Then, we constructed a 4-level categorical exposure variable accounting for predominant wind direction and distance from the well site: living upwind and more than 200 m from OGD wells (reference); living upwind and within 200 m; living downwind and more than 200 m; and living downwind and within 200 m (Model 3). In addition, we considered models with distance modeled as a continuous variable using a lognormal transformation (Model 4). Predominant wind direction in the LA basin is from the west to the east which we confirmed using 5 years (Jan 2015–Jan 2020) of wind speed and direction data from a nearby meteorological station (see Fig. 3). Prior studies have observed high pollution concentrations and gradients on the east side of freeways (Zhu et al., 2002, 2006) and downwind (east) of the OGD facilities (Garcia-Gonzales et al., 2019a). Sensitivity analysis for lung function outcomes was also assessed at 150 m and 400 m.

A list of potential confounders was determined a priori from the available survey variables based on previous literature and biological plausibility (Peters et al., 1999b). Logistic models for the presence of acute respiratory symptoms were adjusted for sex (male/female), age group (<18, 18–60, >60), race/ethnicity (Hispanic/Latinx, Black or Asian), dichotomized residential distance to freeway (<200 m), season (winter, spring, summer or fall), baseline asthma status (yes/no), ever smoker (yes/no), reported indoor environmental tobacco smoke (yes/no) and recent flu or cold symptoms (yes/no). A random effect for household (based on address) was included to account for multiple participants from the same residential address. Using generalized linear models, we examined the relationship between lung function and proximity to oil wells adjusted for age (polynomial spline with 3 degrees of freedom), sex (male/female), race/ethnicity, baseline asthma status (yes/no), ever smoker (yes/no), reported indoor environmental tobacco smoke (yes/no), recent flu or cold symptoms (yes/no), dichotomized residential distance to freeway (<200 m), height (m), weight (lbs) spirometry technician and interactions between age and height, and age and sex. We further examined the effect of distance and direction from the oil well site (using the 4-level categorical exposure variable) on measured FEV1 and FVC in a model stratified by neighborhood.

Finally, we conducted a subgroup analysis based on age groups, sex, race/ethnicity and asthma status. All analyses assumed a 2-sided alternative hypothesis at a 0.05 level of significance. All statistical analyses were conducted using R statistical computing language (R Core Team, 2020) version 3.6.2.

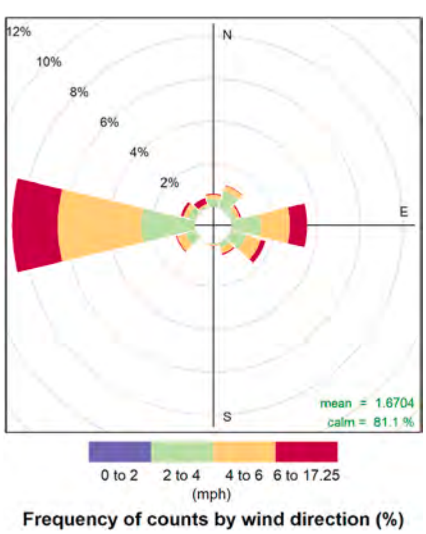

Fig. 3. Wind rose showing wind direction and speed based on 5 years of data (Jan 2015–Jan 2020) from a meteorological station located at the USC University Park Campus, <5 km from the study sites. Direction was reported when wind speeds were >0 mph.

3. Results

3.1. Characteristics of the study population

A total of 972 residents participated in this study to measure lung function and self-reported acute mental and physical health symptoms from 488 distinct addresses (Table 1). 11 participants were subsequently excluded for living outside of the study area after subsequent confirmation of residential address. The mean age of the participants was 39 years with 29% of the participants being children (<18 years) and 22% over the age of 60. The majority (62%) were female and 100% identified as people of color including 792 Hispanic/Latinx, 115 Black/African Americans, and 54 Asians/Asian Americans (51 identified as Korean and 3 as South Asian). On average, participants had lived in the neighborhood for 19 years. 68% of the participants completed the survey in Spanish. Overall, 15% of participants reported a doctor diagnosis of asthma. 21% of participants were ever smokers and 6% reported environmental tobacco smoke inside of the home. More than 70% of participants were nonworkers (e.g. student, homemaker, retiree or unemployed). The median distance from the respective well sites to residences was 291 m. Participants living near the neighborhood with the active drill site were, on average, slightly older and more diverse in terms of race/ethnicity as well as more likely to have ever smoked cigarettes. A total of 288 people lived near (<200 m) an oil well site.

3.2. Self reported acute symptoms

Participants living in the neighborhood with the active OGD wells reported significantly higher prevalence of recent wheeze, daily morning cough, eye irritation, dizziness, fatigue, backache and rash in the past 2 weeks (Table 2) compared to participants living near the idle OGD wells (n = 960). However, we did not observe differences in respiratory symptoms based on proximity to wells, with the exception of sneezing/running nose. Other symptoms unlikely to be related to oil drilling, showed no difference (e.g. trouble hearing, diarrhea) or higher prevalence among the neighborhood with the idle site (e.g. flu or cold symptoms).

In multivariable logistic regression models, we observe that the participants living in the neighborhood with active oil production wells have 2.6 times higher odds (OR 2.58; 95% CI: 1.19, 5.59) of reporting wheezing in the past two weeks compared to participants living in the neighborhood with idle wells. Living near compared to farther from an oil drill site was not statistically significant (OR 1.20; 95% CI 0.69, 2.13) in the model, although living near and downwind was associated with higher odds of recent wheeze (OR 2.26; 95% CI: 1.14, 4.49, Fig. 4, Table S1). In the multivariable models we did not observe consistent significant differences by neighborhood or distance for morning cough (Table S2). We did observe that participants living downwind of the well sites had higher odds of reporting sleep disturbance due to wheezing over the past two weeks (downwind and <200 m: OR 2.91, 95% CI 1.20, 7.06, Table S3).

Table 1
Characteristics of participants by neighborhood and well proximity.

	North University Park (idle)	Jefferson Park (active)	Near Well (<200 m)	Farther from Well (>200–1000 m)
	N = 441	N = 520	N = 288	N = 673
Age categories, N (%):				
9 - 18	138 (31.3%)	136 (26.1%)	56 (19.4%)	218 (32.4%)
18-60	243 (55.1%)	212 (40.8%)	133 (46.2%)	322 (47.8%)
60 <	60 (13.6%)	172 (33.1%)	99 (34.4%)	133 (19.8%)
Gender, N (%):				
Female	286 (64.9%)	310 (59.5%)	180 (62.5%)	416 (61.8%)
Male	155 (35.1%)	210 (40.5%)	108 (37.5%)	257 (38.2%)
Race/Ethnicity, N (%):				
Asian/Asian American	2 (0.4%)	52 (10.0%)	48 (16.7%)	6 (0.9%)
Black/African American	6 (1.4%)	109 (21.0%)	40 (13.9%)	75 (11.1%)
Hispanic or Latinx	433 (98.2%)	359 (69.0%)	200 (69.4%)	592 (88.0%)
Employed, N (%)	132 (29.9%)	144 (27.7%)	74 (25.7%)	202 (30.0%)
Duration (years) of residence in the neighborhood, Median [25th; 75th]	10.0 [5.0; 17.0]	24.5 [12.0; 40.0]	14.0 [7.0; 27.0]	14.0 [7.0; 33.0]
Ever smoker, N (%)	70 (15.9%)	138 (26.5%)	74 (25.7%)	134 (19.9%)
Current smoker, N (%)	19 (4.3%)	35 (6.7%)	16 (5.6%)	38 (5.6%)
Exposed to environmental tobacco smoke, N (%)	38 (8.6%)	21 (4.0%)	17 (5.9%)	42 (6.2%)
Allergic rhinitis/Hay fever, N (%)	71 (16.1%)	132 (25.4%)	78 (27.1%)	125 (18.6%)
Doctor diagnosis of asthma, N (%)	57 (12.9%)	85 (16.3%)	50 (17.4%)	92 (13.7%)
Distance to the closest freeway, N (%):				
≥200 m–1000 m	235 (53.3%)	480 (92.3%)	228 (79.2%)	487 (72.4%)
<200 m	206 (46.7%)	40 (7.7%)	60 (20.8%)	186 (27.6%)
Distance from well, m, Mean (SD)	308 (224)	380 (238)	162 (42)	396 (156)
Distance from well, categorial, N (%)				
≥200 m–1000 m	268 (60.8%)	405 (77.9%)	–	673 (100%)
<200 m	173 (39.2%)	115 (22.1%)	288 (100%)	–
Direction from well, N (%)				
Upwind	174 (39.5%)	175 (33.7%)	55 (19.1%)	294 (43.7%)
Downwind	267 (60.5%)	345 (66.3%)	233 (80.9%)	379 (56.3%)
Households, N	205	283	163	325

Table 2
Self-reported acute symptoms among participants by neighborhood and well proximity.

	North University Park (idle)	**Jefferson Park (active)**	**Near Well (<200 m)**	**Farther from Well (>200–1000m)**
	N = 442	***N = 518***	***N = 288***	***N = 672***
Wheeze & Bronchitic Symptoms				
Wheezing/ whistling in the chest	57 (12.9%)	95 (18.3%) *	50 (17.4%)	102 (15.2%)
Morning cough, every day	110 (24.9%)	105 (20.3%)*	67 (23.2%)	148 (22.0%)
Sleep disturbed by wheeze	43 (9.7%)	69 (13.3%)	39 (13.5%)	73 (10.9%)
Other Respiratory Symptoms				
Sore throat	157 (35.5%)	181 (34.9%)	91 (31.6%)	247 (36.8%)
Chest tightness	76 (17.2%)	112 (21.6%)	56 (19.4%)	132 (19.6%)
Sneezing or runny nose	175 (40.0%)	207 (40.0%)	132 (45.8%)	250 (37.2%)*
Recent cold or flu symptoms during spirometry	151 (34.2%)	98 (18.9%) *	79 (27.4%)	170 (25.2%)
Mucous-membrane irritation				
Irritation of the eyes	184 (41.6%)	276 (53.3%)*	144 (50.0%)	316 (47.0%)
Irritation of the nose	168 (38.0%)	213 (41.1%)	117 (40.6%)	264 (39.3%)
Neurological				
Dizziness	114 (25.8%)	176 (34.0%)*	91 (31.6%)	199 (29.6%)
Headache	222 (50.2%)	242 (47.1%)	130 (45.1%)	334 (49.7%)
Fatigue	177 (40.0%)	241 (46.7%)*	144 (50.0%)	274 (40.1%)*
Ringing of the ears	125 (26.5%)	156 (30.1%)	87 (30.2%)	194 (28.9%)
Seizure	8 (1.8%)	6 (1.2%)	4 (1.4%)	10 (1.4%)
Gastrointestinal				
Diarrhea	43 (9.7%)	78 (15.1%) *	39 (13.5%)	82 (12.2%)
Nausea or Vomiting	40 (9.0%)	53 (10.2%)	19 (6.6%)	61 (9.1%)
Other				
Nosebleeds	45 (10.2%)	67 (12.9%)	22 (7.6%)	90 (13.4%)*
Backache	188 (42.5%)	251 (48.5%)*	144 (50.0%)	295 (43.8%)
Rash	47 (10.6%)	84 (16.2%) *	43 (14.9%)	88 (13.1%)

* chi-square test, $p < 0.05$.

Among other symptoms analyzed with the adjusted logistic models, we identify significantly higher odds of sore throat (OR 2.04; 95% CI 1.19, 3.51), chest tightness (OR 3.16; 95% CI 1.54, 6.48), irritation of the eyes (OR 3.08; 95% CI 1.775.30), irritation of the nose (OR 2.23; 95% CI 1.31, 3.82), dizziness (OR 3.01; 95% CI 1.53, 5.90) and ringing of the ears (OR 1.74, 95% CI 1.05, 2.88) among residents in the neighborhood with the active drill site. The other symptoms were not statistically significant for neighborhood site in multivariable models, including symptoms thought to be unrelated to the well activity (e.g. backache and trouble hearing) (Table S4). We do not observe proximity alone to be a significant predictor of self-reported acute symptoms after adjusting for other covariates.

3.3. *Pulmonary function results*

Of the study participants, 919 performed at least one spirometry test. 172 participants were excluded because of restrictions in age (included only participants ages 10 to 85, n = 26) or due to invalid/outlier

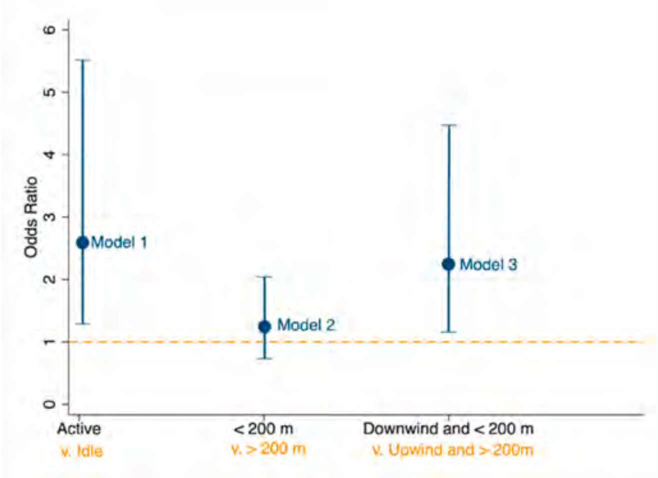

Fig. 4. The odds ratio and 95% confidence interval for recent wheeze for Model 1) participants living in the neighborhood with the active compared to the idle OGD well sites; Model 2) participants living near (<200 m) the OGD well sites compared to those living farther away (200–1000 m); and Model 3) participants living both near (<200 m) and downwind of an OGD well site compared to those living farther (200–1000 m) and upwind. All models are adjusted for age, sex, race/ethnicity, asthma diagnosis, recent flu/cold, season, ever smoker, recent exposure to environmental tobacco smoke and living near a freeway. Models include a random effect for residential household.

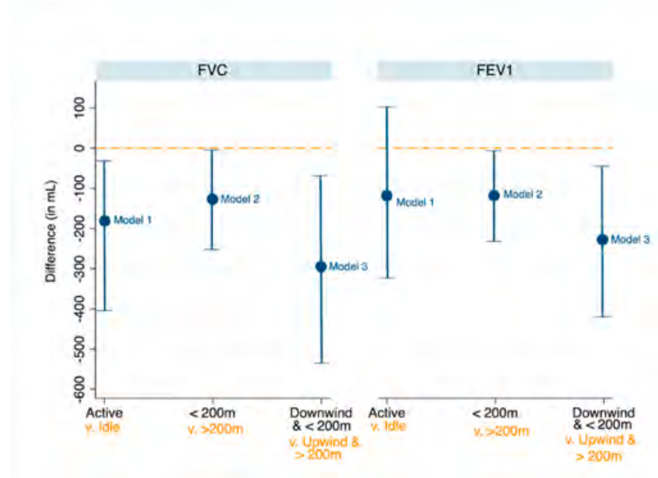

Fig. 5. The difference in average FEV1 and FVC (in mL) and 95% confidence interval for Model 1) participants living near the neighborhood with the active compared to the idle OGD sites; Model 2) participants living near (<200 m) the OGD sites compared to those living farther away (200–1000 m); and Model 3) participants living both near (<200 m) and downwind of an OGD site compared to those living farther (200–1000 m) and upwind. All models are adjusted for age, height, age-height interaction, sex, race/ethnicity, weight, asthma diagnosis, recent flu/cold, ever smoker, indoor exposure to environmental tobacco smoke, living near a freeway, season, spirometry technician and a random effect for residential household.

pulmonary function measurements that did not meet the ATS criteria (n = 146). Mean FEV1 and FVC for males were 2773 mL and 3654 mL, respectively, and the corresponding means for females were 2220 mL and 2875 mL.

In multivariable linear models, participants living near the active oil wells had, on average, a −188 mL FVC (95% CI: −405, −28) and −110 mL FEV1 (95% CI: −286, 66) difference compared to the idle site suggesting significantly lower FVC values among residents near the active site. After considering proximity, we observe that residents living near (<200 m) oil well sites had, on average, −128 mL lower FVC (95% CI: −282, −5) and −112 mL lower FEV1 (95% CI: −213, −10) compared to residents living more than 200 m from the wells (Fig. 4). When accounting for predominant wind direction and proximity, we observe that residents living downwind and less than 200 m from oil operations had, on average, −296 mL lower FVC (95% CI: −525, −67) and −236 mL lower FEV1 (95% CI: −425, −48) compared to residents living upwind and more than 200 m from the wells (Fig. 5, Table S6). Participants living downwind 200–1000 m from the site also had, on average, significantly lower FVC (β = −253 mL, 95% CI: −384, −123) and FEV1 (β = −207 mL, 95% CI:− 314, −100) than those upwind and farther away. Further, living upwind and close (<200 m) from the well sites was also associated with a significantly reduced FEV1 and FVC lung function measurements (Table S6). Examining distance from the well site using a continuous log transformed metric per 100 m, we find that a twofold increase in the distance away from the site improves FVC by 92 mL (β = 133 95% CI: 30.3, 236.2); FEV1 values are positively associated with an increase in the distance from the OGD site but not statistically significant (β = 72; 95% CI: −13.9, 157.1) (Table S7).

Among the multivariable linear regression models stratified by neighborhood, we found that living within 200 m of the active wells (Jefferson Park, Table S8) was associated with significantly lower mean FVC (β = −278 mL, 95% CI: −502, −55) and FEV1 (β = −240 mL, 95% CI: −439, −42) compared to more than 200 m away from the wells. A similar pattern was observed when examining downwind participants, where those living downwind and near (<200 m) the active oil wells had significantly lower mean FVC (β = −399 mL, 95% CI: −652, −147) and FEV1 (β = −414 mL, 95% CI: −636, −191) compared to living upwind and more than 200 m away from the wells after adjusting for covariates (Fig. 6). The pattern largely persistent among participants in the neighborhood with the idle wells (Fig. 6, Table S9). Among participants in the neighborhood near the idle wells, which is impacted by multiple freeways, we found that residents living downwind and close to the idle wells was associated with lower lung function (FVC: β = −297 mL, 95% CI: −577, −18; FEV1: β = −284 mL, 95% CI: −490, −76).

3.4. Sensitivity analyses

We assessed lung function using two additional proximity distances: 150 m and 400 m. The associations observed with lung function persists in similar direction (Table S10 and S11). The difference in FEV1 among participants living <150 m from the well site are similar (β = −187 mL, 95% CI: 332, −42) when compared to the results using the <200 m distance. We observe the difference attenuate for FEV1 at the 400 m distance (β = −21 mL, 95% CI: 119, 82). Across both analyses, a significantly lower lung function was observed among those living nearby and downwind of the oil well facilities.

In addition, significant effects with respect to distance and direction from oil operations and lung function were seen across subgroups (Table 3), including among participants without asthma. In an analysis restricted to participants without asthma, the difference in the effect of living near and downwind of an OGD well site was similar to that of the entire study population (−271 mL lower FEV1 and -326 mL lower FVC on average). We observed the effects of oil and gas wells on FEV1 lung function, on average, to be significant among adults, Latinx residents and participants over 60 if living downwind and <200 m from a well site.

4. Discussion

Although petroleum extraction is increasingly common in urbanized areas, few studies exist on the health consequences for nearby residents (Colborn et al., 2011; McKenzie et al., 2012; Werner et al., 2015). In this community-driven epidemiological study, we report both self-reported acute symptoms and pulmonary function measurements of a diverse cohort of residents living near both an active and idle drill site that draw

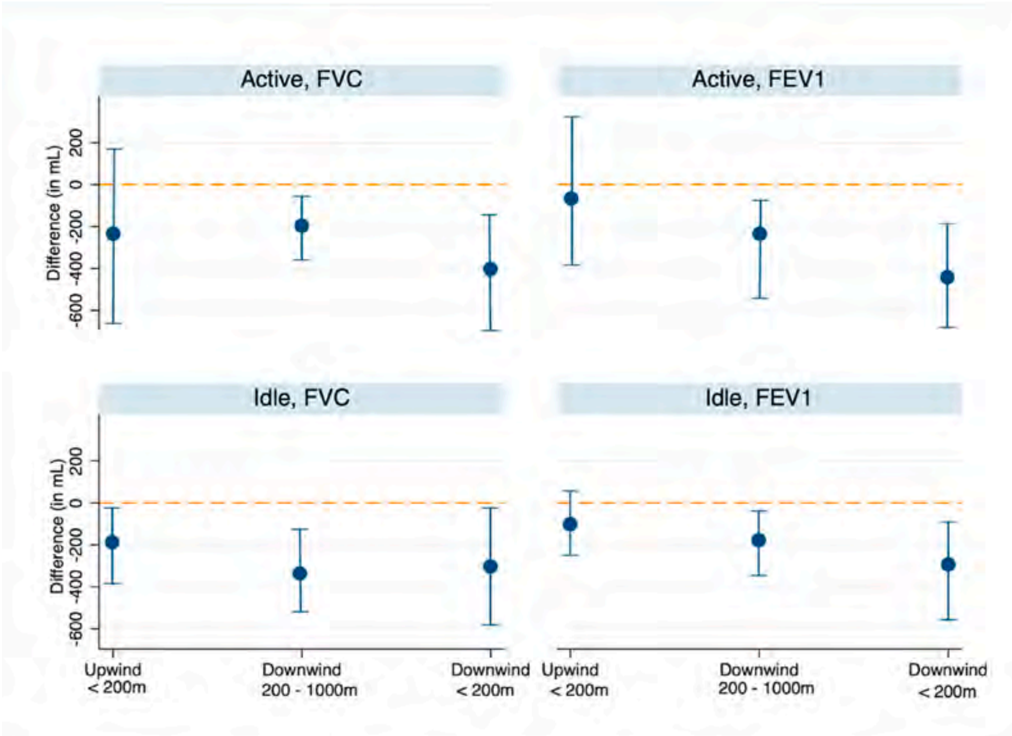

Fig. 6. Average difference in FEV1 (left) and FVC (right) in mL compared to participants living upwind and 200–1000 m from the OGD site stratified by neighborhood. Top row show results for participants living near the active OGD site (Jefferson Park neighborhood) and bottom row is among participants living near the idle OGD site (North University Park). The reference category is living upwind and more than 200 m from an OGD site. Models are adjusted for age, height, age-height interaction, sex, race/ethnicity, weight, asthma diagnosis, recent flu/cold, ever smoker, indoor exposure to environmental tobacco smoke, living near a freeway, season, spirometry technician and a random effect for residential household.

Table 3
Multivariate subgroup analyses of oil site distance and direction effects ond differences in FEV_1 and FVC (reported in mL).

	FVC[a]			FEV_1[a]		
Subgroups	Downwind <200 m	Downwind 200–1000 m	Upwind <200 m	Downwind <200 m	Downwind 200–1000 m	Upwind <200 m
Age						
9- <18	−234 (−495, 37)	**−292 (−495, −89)**	−8 (−396, 379)	−163 (−378, 51)	**−180 (−347, −13)**	−51 (−369, 266)
18-60	**−225 (−419, −32)**	−157 (−334, 20)	−251 (−566, 63)	**−290 (-570, -8)**	**−169 (−327, −12)**	**−219 −394, −45)**
>60	−303 (−669, 62)	−339 (−734, 55)	−275 (−806, 256)	**−303 (−266, −40)**	**−284 (−569, −0.5)**	−170 (−552, 212)
Sex						
Female	−158 (−335, 19)	**−158 (−335, −46)**	−162 (−449, 114)	**−194 −332, −55)**	**−161 (−283, −39)**	−170 (−390, 50)
Male	**−435 (−863, −7)**	−276 (−393, 3)	**−313 (−589, −37)**	−236 (−603, 131)	**−224 (−457, −32)**	−160 (−395, 75)
Race/Ethnicity						
Latinx	**−298 (−544, −54)**	**−271 (−412, −125)**	**−208 (−373, −42)**	**−264 (−459, −69)**	**−205 (−319, −91)**	**−176 (−308, −44)**
Black	−305 (−717, 108)	−476 (−1015, 61)	367 (−823,1557)	−330 (−681, 20)	−397 (−854, 61)	438 (−574,1450)
Asthma status						
Yes	−263 (−591, 72)	−69 (−378, 239)	−122 (−591, 346)	**−380 (−662, −99)**	−276 (−558, 5)	77 (−350, 504)
No	**−326 (−601, −52)**	**−271 (−420, −123)**	**−232 (−401, −63)**	**−271 (−498, −46)**	**−191 (−313, −69)**	**−171 (−331, −32)**

[a] Models were adjusted for age, height, age-height interaction, sex, race/ethnicity, weight, asthma diagnosis, recent flu/cold, smoking, exposure to indoor environmental tobacco smoke, site, living near a freeway, season and spirometry technician. A random effect was included for residential household. Stratifying variables were excluded from their respective model runs.

from Las Cienagas oil field in urban South Los Angeles. We identify that residents living near the active drill site report more acute symptoms, including wheezing, sore throat, chest tightness, dizziness and eye or nose irritation compared to their counterparts living near the idle wells. Furthermore, residents living closer to the OGD operations have, on average, lower lung function compared to the residents farther away. While this pattern is more pronounced near the actively producing site, we see persistent effects in both neighborhoods. The impacts on lung function were further observed among non-asthmatic participants, indicating that oil-related activity may have adverse effects on otherwise healthy people. This study provides evidences of potential adverse relationship between respiratory health and oil drilling activities in an urban context.

Our findings in this study in an urban context suggest that resident self-reported health symptoms are similar to those reported through surveys nearby natural gas and hydraulic fracturing sites in more rural settings. Results from three recent health surveys in the US observed symptoms of throat and nasal irritation, eye burning, sinus problems, headaches, skin problems, loss of smell, cough, nosebleeds and stress as more common among individual living closer to extraction sites compared to those living farther away (Steinzor et al., 2013; Rabinowitz et al., 2015; Ferrar et al., 2013). Survey-based studies documented higher rates of headaches, dizziness, and eyes, nose, throat and skin irritation among residents in oil producing regions compared to people living farther away in Ecuador (San Sebastián et al., 2001) and Nigeria (Kponee et al., 2015). Elevated incidence of pediatric asthma hospitalization has also been observed in nonurban areas with the highest levels of drilling activity, suggesting an association between extraction activity and respiratory health (Willis et al., 2018).

A single well typically operates for decades (often more than 60 years in CA) with neighbors facing impacts from construction, production, processing and transportation. Such operations produce a complex mixtures of pollutants including carcinogens, mutagens, reproductive, developmental toxins and endocrine disruptors (Garcia-Gonzales et al., 2019b; Johnston et al., 2019; Colborn et al., 2014; Macey et al., 2014). Hazardous compounds can be volatilized or aerosolized during extraction via active evaporating pits, flares, surface spills, processing, and transportation (Colborn et al., 2014). Research near Las Cienagas oil field identified both combusted (e.g. traffic) and volatilized hydrocarbons were affecting air quality throughout the community and revealed episodic peaks of methane and VOCs likely attributable to local oil and gas operations (Collier-Oxandale et al., 2020). Studies of acute inhalation exposures to petroleum hydrocarbons in occupational settings as well as among residents living near refineries, oil spills or gas stations have found increased risks of eye irritation and headaches (Kim et al., 2009; Tunsaringkarn et al., 2013) and asthma symptoms (White et al., 2009; Rovira et al., 2014; Wichmann et al., 2009). In additional reviews of non-occupational exposures to ambient levels of benzene and other petroleum hydrocarbons found adverse impacts to the respiratory health of children (Ferrero et al., 2014) and respiratory dysfunction and endocrine disruption among adults (Bolden et al., 2015).

Occupational exposure in the petroleum industry is associated with a higher prevalence of respiratory and nasal symptoms, and lung function impairment (Stoleski et al., 2011). Decrease in lung function has been documented among children living near petrochemical industries (Rusconi et al., 2011) and among children living near gas-flares and oil spills (Aweto et al., 2019) compared to those in a reference communities. In a community-based study across five states, multiple volatile organic compounds (VOCs) were measured at concentrations exceeding a chronic risk level threshold (Macey et al., 2014). Evidence suggests that exposure to VOCs may adversely affect pulmonary function (Elliott et al., 2006; Yoon et al., 2010; Cakmak et al., 2014). Stagnant air patterns have also been associated with health impacts in regions with unconventional natural gas development (Brown et al., 2015). While the mechanisms of VOC toxicity are still being understood, some research indicates oxidative stress having a role (Garçon et al., 2006; Coleman et al., 2003; Röder-Stolinski et al., 2008). Reduced lung function has been associated with subsequent increased risk of overall mortality including coronary artery disease and respiratory disease (Islam et al., 2007; Knuiman et al., 1999; Sin et al., 2005). A small study in rural Colorado found preliminary evidence of adverse cardiovascular impacts, including higher augmentation index and blood pressure, among adults near the most drilling activity in this cross-sectional community study (McKenzie et al., 2019).

Los Angeles houses a dense, diverse population living in close proximity to oil extraction (Elkind, 2012). Nonetheless, oil extraction in LA has long been obfuscated from public view even as extraction sites operate within residential zones, hidden by tall walls or landscaped hedges (Elkind, 2012). In recent years, as oil production increased, low-income neighborhoods have raised health concerns. The City of LA requires no buffers or setbacks between oil extraction and homes, and approximately 75% of active oil or gas wells are located within a 500 m distance from "sensitive land uses", such as a home, school, childcare facility, park, or senior residential facility. Recent research leveraging a community air monitoring network in South Los Angeles identified ambient methane concentrations were higher within 500 m of the OGD sites (Okorn et al., 2021). Such elevated concentrations were present at the idle well suggesting fugitive emissions occur even when oil production has ceased (Okorn et al., 2021). There are ~970 active oil or gas wells within 200 m of a residential property in LA County as of 2019 (Fig. 1b). Nonetheless, a prior door to door survey in the Las Cienagas neighborhoods found that 63% of residents would not know how to contact local regulatory authorities in case of a pollution or health concern (Shamasunder et al., 2018b). 45% of respondents in this same survey were unaware of the oil and gas operations in the neighborhood (Shamasunder et al., 2018b).

To our knowledge, this is the first study to examine the relationship between lung function in urban communities and oil well sites. To date the limited health research on oil and gas development in the US is based in rural and majority non-Hispanic White communities. Our study involves a predominantly low-income community of color living in an historically underserved and environmental justice community. Very limited data is available on the impacts of oil drilling in an urban environment (Garcia-Gonzales et al., 2019a; Shamasunder et al., 2018b). In this study we identify proximity to urban oil drilling sites as a factor associated with reduced lung function among nearby residents. To date, researchers have largely relied on assessing health impacts near oil and gas development, such as birth outcomes or hospitalization, using secondary data (Johnston and Cushing, 2020). While limited by a cross-sectional design, our study contributes novel pulmonary function measurements to the epidemiology on health effects of urban oil drilling. However, this analysis faces several limitations. We cannot rule out potential confounding by unmeasured covariates or differential participation rates based on concerns about neighborhood health or environmental quality. We cannot account for lifetime residential history, individual household characteristics nor occupational exposures. Self-reported household income data was not reliable (30% of the data was missing or reported as "I don't know"); therefore this information was not considered in the analysis. Multiple participants per household were allowed as long as they met the inclusion criteria and our modeling only accounted for such differences based on a random effect by residential address. As we only collected address information, and as multiple families often live in one household (or one common address), we could not distinguish unique families. Wind direction and proximity is used as a proxy for exposure to pollution associated with the well sites and may not represent true oil-related exposure. Future work will include assessing neighborhood scale air pollution to better understand potential spatiotemporal patterns of regional, freeway and oil drilling related exposures.

5. Conclusions

Together, our findings suggest that living near urban oil drilling sites is significantly associated with reduced lung function in South Los Angeles. This community-academic research improves understanding of impacts from living nearby drilling operations on the health and welfare of this community, which is critical to inform public health relevant strategies to address community concerns. We observe a similar pattern among those living near the active and idle sites suggesting potential chronic impacts of exposures. As a community of predominantly low-income residents of color, these impacts raise environmental justice concerns about the effects of urban oil drilling. Reducing emissions, increasing the distance between oil operations and residents, and investments in renewable energy and energy efficiency measures that reduce reliance on fossil fuels overall—could protect the lung health of residents near oil wells.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2021.111088.

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Exhibit 8 of 13 - LA County DPH 2018. Public Health and Safety Risks of Oil and Gas

Public Health and Safety Risks of Oil and Gas Facilities in Los Angeles County

Los Angeles County Department of Public Health

February 2018

A tank farm and oil well in the backyard of a house on Firmin Street in Echo Park, California (August 2016)

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Authors

Toxicology and Environmental Assessment Branch, Division of Environmental Health

Katherine Butler, MPH, DABT
Senior Staff Analyst

Carrie Tayour, PhD, MPH
Supervising Epidemiologist

Christine Batikian
Master's Student Intern

Charlene Contreras, REHS
Environmental Health Manager

Mandi Bane, PhD
Staff Analyst

Elizabeth Rhoades, PhD
Director of Climate Change and Sustainability

Evenor Masis, MS, REHS
Industrial Hygienist

Cyrus Rangan, MD, FAAP, FACMT
Director

Environmental Health

Terri Williams, REHS
Director

Office of Planning, Evaluation and Development

Susan Blackwell, MA
Assistant Director

Christine De Rosa, PhD
Senior Planning Analyst

Yeira Rodriguez, MPH, MCHES
Planning Manager

Gayle Haberman, MPH
Director

Health Impact Evaluation Center

Emily Caesar, MPH, MSW
Project Manager

William Nicholas, PhD, MPH, MA
Director

Los Angeles County Department of Public Health

Angelo Bellomo, REHS, QEP
Deputy Director for Health Protection

Paul Simon, MD, MPH
Chief Science Officer

Jeffrey D. Gunzenhauser, MD, MPH
Interim Health Officer

Cynthia A. Harding, MPH
Chief Deputy Director

Barbara Ferrer, PhD, MPH, MEd
Director

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Executive Summary

Oil and gas development in the Los Angeles Basin presents unique public health and safety concerns because some oil and gas reserves lie beneath densely populated urban areas. Future production from these natural reserves will primarily come from existing oil fields, with some potential for the development of undiscovered oil and gas resources using conventional or unconventional methods. This report is intended to provide local policy-makers with an overview of relevant public health research and investigations. It concludes with an overview of measures to reduce potential health impacts.

There are currently 68 active oil fields in the Los Angeles Basin, with facilities operating under a wide range of operational and environmental conditions. While some facilities have been subject to stricter design and mitigation measures, others have not been required to conduct health risk assessments or other environmental studies. In some neighborhoods, such as South Los Angeles, residences are located only several feet away from the boundary of a drilling site and as close as 60 feet from an active oil well. Two smaller neighborhood facilities, which the Los Angeles County Department of Public Health (DPH) has responded to concerns or complaints, were found in a state of disrepair with environmental conditions that impact the health of neighboring residents.

In this report, DPH synthesized information from multiple lines of evidence, including a review of epidemiological literature, environmental and health impact assessments, neighborhood health investigations, and consultations with various jurisdictions regarding oil and gas ordinances. The scope of each is described below.

Epidemiological Literature: The review of the scientific literature synthesizes information from epidemiological studies and other published reviews on the potential health impacts associated with living near oil and gas activities. These peer-reviewed studies examine a variety of short-term and long-term health indicators such as birth outcomes; cancer; and respiratory, neurological, gastrointestinal, dermatological, and psychological effects. While epidemiological studies have found limited associations between adverse health effects and living near oil and gas operations, high-quality exposure data measured over long periods of time is lacking. Therefore, the epidemiological studies are not able to conclude whether or not living near oil and gas activities is associated with long-term health impacts.

Environmental and Health Impact Assessments: These impact assessments help to fill data gaps in the literature by predicting potential health and safety impacts from air emissions, odors, noise, vibration, and other environmental hazards associated with oil and gas development projects. However, it should be noted that conventional risk assessment tools can be limited in their ability to anticipate certain risks given the complexity of health and quality-of-life consequences and the need for more robust, local-level monitoring data. The mitigation measures proposed for specific projects can be used to inform policies and plans involving oil and gas activities and operations that do not require such assessments to avoid or minimize potential adverse impacts.

Neighborhood Health Investigations: When DPH is notified of environmental or operational conditions at industrial facilities that may pose a threat to public health, DPH conducts a neighborhood health investigation and recommends action to protect and preserve public health. In response to community health complaints, DPH conducted two neighborhood health investigations of oil and gas facilities located in densely populated communities. In both investigations, DPH responded to resident health complaints of headaches, nausea, vomiting, respiratory irritation, and eye, nose and throat irritation. Such impacts often warrant immediate action to protect health. These two neighborhood health investigations revealed insufficient regulatory oversight and inadequate mitigation measures to reduce exposures and associated impacts in the adjoining community.

Consultations with Other Jurisdictions: To understand oil and gas ordinances adopted by other jurisdictions, DPH conducted one-on-one interviews with 10 jurisdictions throughout the nation and convened one joint meeting. These jurisdictions have established requirements, such as setback distances and/or mitigation measures, to limit adverse health and safety impacts of oil and gas production.

DPH determined that there is sufficient evidence to provide the following guidance for oil and gas facilities in order to protect health:

1. Los Angeles County and local jurisdictions within the County should expand the minimum setback distance beyond 300 feet, as currently specified in local zoning code, and apply these requirements to both the siting of new wells and to the development of sensitive land uses near existing operations. It is important to note that a setback distance is not an absolute measure of health protection and additional mitigation measures must also be considered. For existing oil and gas operations, a site-specific assessment at each facility throughout the County is necessary to identify current distances to sensitive land uses and other site characteristics that can be used to inform whether further mitigation measures are warranted to reduce potential public health and safety risks.

   Table ES-1 below summarizes various setback distances, mitigation targets, remaining hazards and whether additional mitigation measures could further reduce potential adverse impacts.

Table ES-1. Review of Key Public Health and Safety Hazards and Setback Distance Guidance

Setback Distance	***Air Quality***	***Noise***	***Odors***	***Fires, Explosions, and Other Emergencies***	***Additional Mitigation and Assessment Notes***
300 feet					Some health and safety impacts may still be unavoidable regardless of additional mitigation.
600 feet	✓				Additional mitigation and assessment would likely be needed to avoid most impacts. Odors may be unavoidable, regardless of mitigation. Air monitoring is advised.
1,000 feet	✓	✓			Additional mitigation and assessment may be needed to avoid noise impacts during certain operations, e.g. well advancement. Odors may be unavoidable in loss of containment events, regardless of additional mitigation.
1,500 feet	✓	✓	✓		Additional mitigation not likely to be needed. Some uncertainty remains due to gaps in long-term health and exposure data.

This table is based on information compiled from scientific publications,[13,37,51,52] environmental impact assessments,[27-33] other environmental studies,[10,16,20,34,35,36,46] and experiences in other jurisdictions.

✓ Represents the distance at which the impact is likely mitigated

2. In coordination with the California Air Resources Board (CARB) and the South Coast Air Quality Management District (SCAQMD), Los Angeles County should require the operators of facilities within urban areas of the County to implement continuous air monitoring systems around oil and gas operations to:

    - Measure air pollutants released by oil and gas operations;
    - Ensure oil and gas sites comply with environmental regulations;
    - Evaluate the impact of releases from oil and gas sites on surrounding neighborhoods; and
    - Monitor setbacks for these sites regularly, based on air monitoring and emerging science, and revise setback distances and/or other mitigation requirements when necessary to protect public health.

    It should be noted that SCAQMD has imposed some requirements related to public notification and monitoring, but only after concerns are identified at a particular oil and gas operation, such as odor complaints. Current monitoring and enforcement activities can be sporadic, and it is difficult to understand long-term exposure risks for people living near oil and gas operations in the absence of continuous monitoring. To better characterize air quality in communities near oil and gas operations, SCAQMD completed a fenceline monitoring study and CARB launched the Study of Neighborhood Air near Petroleum Sources (SNAPS); results from these efforts should be used to inform air monitoring policies.

3. A variety of state and federal regulations require routine inspections, maintenance, testing and leak detection systems for oil and gas facilities; however, local oversight of these regulations is limited. Optimal local oversight would reduce public health and safety risks associated with aging infrastructure, and should include a local auditing and certification process, streamlined coordination, and data sharing among agencies. A local auditing program would confirm that operators are complying with federal, state and local regulations.

4. Operators should prepare and make available to the public a comprehensive Community Safety Plan, in coordination with City and County departments, including Fire, Building and Safety, and Law Enforcement. These plans should include information on hazardous chemicals stored onsite; air emission monitoring efforts; and health-based thresholds to identify the need for additional mitigation. For operations to plug wells permanently or to perform well maintenance, the responsible party should also prepare and implement a Community Safety Plan. The Community Safety Plan should facilitate communication and input from local stakeholders, and be submitted to DPH for review and approval. The Plan should include protocols and procedures for immediate notification to the County Health Officer in the event of odor or health complaints.

5. Operators should maintain enhanced Emergency Preparedness Plans that account for proximity to sensitive land uses. These plans must include communication procedures to immediately notify local government agencies of any emergencies, such as spills or other releases.

To further inform health-protective policies and regulations, DPH will collaborate with County partners, local and state enforcement agencies, and interested stakeholders. DPH recommends site-specific assessments at existing oil and gas operations located near sensitive land use to determine the appropriate combination of setback distance and additional mitigation measures, as well as the extent to which these measures are sufficient to protect public health.

I. Introduction

Oil and gas development in the Los Angeles Basin presents unique public health and safety concerns because some oil and gas reserves lie beneath densely populated urban areas. Future production from these natural reserves will primarily come from its 68 active oil fields, with some potential for the development of undiscovered oil and gas resources using conventional or unconventional methods.[1,2] Public concern has led to recent legislation and rules to assess the health and safety risks of oil and gas production, including California Senate Bill 4 to assess unconventional well stimulation treatments[3] and South Coast Air Quality Management District (SCAQMD) Rule 1148.2 requiring oil and gas operators to report chemicals used in drilling, rework, or completion processes.[4]

Health and safety risks of oil and gas production are particularly relevant to residents of Los Angeles County, which is the second largest oil producing county in California.[5] There are 3,468 active and 1,850 inactive oil and gas wells countywide.[5] Although oil and gas production in Los Angeles County occurs in both rural and urban areas, the potential public health impacts of oil and gas sites located in densely populated areas are concerning, particularly to those who experience disproportionate economic and health inequities.

Some communities within Los Angeles County have developed and adopted ordinances to regulate oil and gas drilling within their jurisdictions. One example is the Baldwin Hills Community Standards District that was adopted in 2008 for the Inglewood Oil Field, the largest urban oil field in the U.S. This site has undergone extensive environmental review and operates under a set of regulatory requirements to ensure ongoing monitoring of air quality, groundwater, noise, and seismic activity; establish setback distances from sensitive areas and emergency response protocols; and hold monthly meetings with a community advisory panel.[6] Wells in other parts of the county are not subject to the same level of oversight, and operate with various permit conditions and regulations depending on the project.[7]

On March 29, 2016, the Board passed a motion instructing the departments of Regional Planning, Fire, Public Health, and Public Works to convene an Oil and Gas Strike Team to assess the conditions, regulatory compliance, and potential public health and safety risks associated with existing oil and gas facilities in the unincorporated areas of Los Angeles County.[7] DPH participated in site assessments with regulatory agencies as an active member of the Oil and Gas Strike Team. A key component of the motion is an assessment of the potential public health and safety risks using a Public Health Screening Assessment (Appendix A). This is a complex task, considering (1) the wide variety of oil and gas operations encountered across the County; (2) the proximity of people living, working and going to school near operations; (3) the multitude of potential chemical and physical hazards if operations and storage are not properly managed; and (4) uncertainties with regards to a lack of long-term exposure and health data.

The Oil and Gas Strike Team conducted site visits to 15 oil and gas facilities currently operating in unincorporated Los Angeles County, including 68.5% of wells identified for review (557 out of 813 wells). An additional nine facilities operating in the unincorporated County were not inspected by the Oil and Gas Strike Team because access was not granted by the operators. The Public Health Screening Assessment based public health, safety, and environmental risks primarily on four priority areas: the facility's hydrogen sulfide gas content in production, operating pressures of wells and equipment, drilling frequency, and proximity to nearby populations.

Among the sites visited by the Oil and Gas Strike Team, the final report notes that public health risk levels were considered "low" for risks associated with hydrogen sulfide gas, operating pressures, and drilling frequency.[8] Several facilities were ranked "high" by the Public Health Screening Assessment for proximity to residences or sensitive receptor locations. Notably, the Oil and Gas Strike Team found that six of the 15 facilities had wells or tanks less than 300 feet from the nearest residence or school; two of those sites had more than 60 wells situated less than 300 feet from occupied structures.[8] The County Zoning Ordinance requires a 300-foot setback from residences for drilling oil wells in certain land-use zones;[9] however, the ordinance does not apply to wells drilled prior to its adoption or to wells that preceded construction of nearby structures.

The final report[8] by the Oil and Gas Strike Team recommended that Los Angeles County further evaluate the following key areas:

- Removal of "by right" permitting (as required by the Board Motion)[7]
- Setback distances
- Well stimulation techniques (to reflect state regulations)
- Air quality and odor monitoring
- Transportation of chemicals in residential areas
- Pipeline monitoring and leak detection
- Abandonment of long idle wells
- Emergency Response Plans
- Communication with surrounding community

In addition to participating on the Oil and Gas Strike Team, DPH also consulted with the City of Los Angeles' Petroleum Administrator who is currently assessing the public health and economic impacts of requiring a buffer distance around oil and gas facilities in its jurisdiction. This DPH report is intended to provide local policy-makers with an overview of public health research and investigations to inform potential revisions to local oil and gas ordinances and land use zoning codes.

II. Epidemiological Literature

The epidemiological literature on public health and safety impacts of oil and gas activities has been increasing in recent years; however, data gaps and uncertainties remain. A growth in research over the last decade has been driven by public concern regarding potential environmental and health impacts of specific oil and gas production techniques, such as hydraulic fracturing (i.e. fracking), used to increase output from oil and gas reserves. It is estimated that 26% of active wells in the Los Angeles Basin have been stimulated by methods such as hydraulic fracturing, frac-packing, or high-rate gravel packing.[1]

Future development of the Los Angeles Basin is expected to mainly come from conventional oil reserves in existing fields. Unlike unconventional resources such as “shale oil,” hydraulic fracturing is not routine practice for oil production from conventional resources.[1] However, the public health risks associated with oil and gas operations are not unique to activities that use well stimulation such as hydraulic fracturing. For example, all oil and gas wells use hazardous chemicals and emit toxic air emissions such as benzene, a known human carcinogen.[2] A study of chemical usage data related to oil and gas activities in Southern California found substantial overlap between chemicals used in hydraulic fracturing and those used in routine oil and gas activities such as well maintenance, well completion, or rework.[10] Therefore, this literature review is comprised of epidemiological studies of health impacts from both conventional and unconventional drilling activities.

DPH compiled information from six comprehensive literature reviews[11-16] of epidemiological studies evaluating population health effects from oil and gas activities from peer-reviewed journals and grey literature. These literature reviews focused on evaluating short-term and long-term health indicators such as birth outcomes; cancer; and respiratory, neurological, gastrointestinal, dermatological, and psychological effects. These reviews included studies of oil and gas activities with a wide range of operational and environmental conditions.

A summary of findings from the available literature is described below.

Birth Outcomes

Particulate matter and other toxic air pollutants, such volatile organic compounds (VOCs), have been associated with adverse reproductive and developmental effects.[17,18] A systematic review of 45 studies found strong evidence for the disruption of human sex steroid hormone receptors; and moderate evidence for increased risk of preterm birth, miscarriage, birth defects, decreased semen quality, and prostate cancer.[12] The majority of the studies included in the review examined individual chemicals, complex mixtures of chemicals, and waste products related to conventional oil and gas operations. Other epidemiological studies have evaluated whether living near oil and gas operations during pregnancy is associated with adverse birth outcomes (e.g. preterm birth, low birthweight, or low APGAR scores), but the findings are mixed, with some studies showing an association and others no association.[19] Many of the epidemiological studies have methodological limitations, but given that some of the findings suggest potentially serious health impacts such as birth defects,[17] further study is warranted.

Cancer

Oil and gas activities may expose individuals to airborne emissions of VOCs, such as benzene. Studies have shown that exposure to elevated levels of benzene over many years may increase the risk of developing cancer, particularly acute myelogenous leukemia.[11] However, studies examining associations between oil and gas activities and other cancers in adults and children have resulted in mixed findings or null associations. There is insufficient evidence to quantify the contribution of oil and gas operations to incidence of childhood cancers. Studies are limited in both the ability to determine such an association due to methodological challenges to quantify an individual's exposure over time, and the ability to control for other environmental and genetic factors that may contribute to overall risk of developing cancer. For further information on VOC air emissions and potential cancer health risks, refer to Section III.

Respiratory Effects

Air emissions from local oil and gas wells have been shown to contribute substantially to the pollution burden from stationary sources in Los Angeles County.[20] Particulate matter and VOCs are often associated with oil and gas extraction activities, and can lead to harmful human health effects, including eye, nose and throat irritation; exacerbations of asthma; and other respiratory conditions. These emissions are known to present a more significant health threat to infants and children.[14] A recent review reported mixed evidence of an association between proximity to oil and gas operations and self-reported respiratory symptoms.[16] On the other hand, acute adverse respiratory health effects (e.g. cough, wheezing, breathlessness), have been well documented in emergency response and disaster events, such as oil spills.[21,22] Less is known about long-term health effects after disaster events, but one study found respiratory effects among clean-up workers of an oil spill persisted five years later.[23] There is need for further study of potential respiratory health effects of long-term exposure to air emissions during normal operations, using study methods that do not rely solely on self-reported measures.

Neurological Effects

Inhalation of VOCs emitted during improperly regulated oil and gas activities can lead to neurological effects such as headaches, dizziness, and other impacts to the central nervous system. Studies examining neurological symptoms and exposure to VOCs have relied on hospitalizations and self-reported data, with some studies finding an association and others reporting no association. In a large survey-based study, Tustin et al. found an association between people living near natural gas development activities and migraine headaches.[24] The likelihood of reporting migraines was 43 times greater in the area with the most natural gas development activity compared to an area with no natural gas activity. Although there are major limitations to this study, including bias in self-reported symptoms and other factors that contribute to migraines, the results suggest a potential relationship between natural gas activity and adverse neurological effects.

Gastrointestinal Effects

A limited number of studies have examined gastrointestinal effects, such as nausea or abdominal pain, and proximity to oil and gas activities. Studies of oil spill clean-up workers have documented gastrointestinal symptoms (nausea and vomiting) among the acute health problems related to duration of work and working in a highly polluted zone.[21] The studies to date have not demonstrated an association or have provided insufficient evidence to rule out an association between proximity to oil and gas operations and gastrointestinal symptoms.

Dermatological Effects

Direct contact with petroleum product, such as crude oil, is known to cause skin irritation.[25] A limited number of studies have found associations between living near oil and gas operations and self-reported dermal symptoms.[11] Oily mist releases of crude oil from oil and gas operations[26] may result in oily residue on surfaces that can lead to skin irritation if people come in direct contact with the impacted areas.

Psychological Effects

Oil and gas activities can adversely affect the mental health, well-being, and quality of life for nearby residents. Multiple factors, including both chemical and non-chemical stressors, may contribute to increased risk of suffering from depression, anxiety, fatigue, and sleep deprivation. Hays et al. reviewed health impacts of noise exposure near oil and gas activities and found a link between noise levels from such operations and increases in reported sleep disturbance.[13] Tustin et al. found an association between living near oil and gas activities and symptoms of fatigue.[24] Studies examining associations between proximity to oil and gas activities and self-reported psychological effects have offered mixed results.

Limitations of Health Studies

Determining a link between oil and gas production and health impacts based on reviews of the literature is challenging because of the inherent limitations of epidemiological studies. The analyses in these studies typically cannot confirm whether past exposures to chemicals from oil and gas activities are associated with health effects among nearby residents, because of the limitations associated with small sample sizes, and the inability to reliably detect small increases in risk. There is also typically a lack of information on individual levels of exposure to emissions to establish dose-response curves and temporal relationships, as well as other factors that could cumulatively influence health risk, including exposure to the same chemicals from other sources, such as local vehicle traffic.

Summary

Epidemiological studies are observational, and by themselves cannot determine causal relationships between exposures from oil and gas production and specific health effects; however, they provide useful information to guide future research. Studies with well-designed exposure monitoring and measurements are needed to elucidate the actual health implications for populations near oil and gas sites. Meanwhile, acute adverse health effects have been well documented in emergency response and disaster events involving oil and gas operations such as oil spills.[9,21,22] The literature to date provides limited evidence to link adverse health effects to living near oil and gas operations; however, quality exposure data that measures people's exposure over long periods of time is missing. Findings from existing epidemiological studies are not able to conclude whether or not living near oil and gas activities is associated with long-term health effects, but rather highlight the need for further research. Given the limitations of epidemiological studies, comprehensive exposure monitoring of oil and gas activities is needed, and precautionary measures are appropriate to minimize exposures to substances that may adversely affect health.

III. Environmental and Health Impact Assessments

DPH evaluated seven Environmental Impact Reports (EIRs)[27-33] and two Health Impact Assessments (HIAs)[34,35] conducted for conventional and unconventional oil and gas production sites primarily in California from 2008 to 2017. Additionally, DPH reviewed a comprehensive health risk assessment recently completed by the Colorado Department of Public Health and Environment (CDPHE).[16] EIRs and HIAs are particularly helpful in providing an indication of potential public health risks until more comprehensive exposure monitoring and high-quality health studies can be conducted.

Air pollution

The release of chemicals into the air from oil and gas activities can occur from surface operations, wells and pipelines, operation of diesel or gas-powered equipment and vehicles, as well as accidental releases. Primary air pollutants include nitrogen oxides, particulate matter, benzene, toluene, ethylbenzene, xylene, hexane, and polycyclic aromatic hydrocarbons. Over 300 chemicals associated with drilling fluids present public health concerns ranging from respiratory health effects to development of cancer, if not properly monitored and controlled.

Data on air emissions from oil and gas sites at the local level are limited. One air monitoring study looked at particulate matter, heavy metals, and VOCs near Los Angeles' Inglewood Oil Field, noted a "marginal" contribution of particulate matter and "negligible" contribution of metals as compared to air emissions monitored throughout the Los Angeles region.[36] Note that the VOC sampling duration was only two weeks, making interpretation limited for comparison with annual averages used in regional air monitoring data. The CARB is launching a Study of Neighborhood Air near Petroleum Sources (SNAPS) to better characterize emissions of VOCs and other air pollutants from oil and gas wells throughout California.

Some studies indicate that oil and gas wells are substantial contributors to the local air pollution burden from VOCs in the Los Angeles area.[20,37] In the 2015 FluxSense Study, the SCAQMD monitored air quality around 61 sites and estimated that oil and gas wells contribute to more than half of the estimated VOC emissions from stationary sources.[20] This differs from previous estimates presented in the SCAQMD 2016 Air Quality Management Plan that utilized emission inventory data and concluded oil and gas wells contribute to 1% of VOCs from stationary sources.[38] While the 2015 FluxSense project notes uncertainties associated with its method of scaling data to represent the Los Angeles Basin as a whole, it suggests that emissions of VOCs from oil and gas sites may be considerably underestimated compared to emission inventories, and further study is warranted.

The Colorado Department of Public Health and Environment recently conducted a comprehensive health risk assessment using statewide air emissions data.[16] Non-cancer[*] and cancer[†] health risk estimates were calculated for 62 priority chemicals measured at distances of 500 feet or greater from oil and gas operations with a wide range of conditions and mitigation measures. Although the Colorado study concluded that non-cancer and cancer health risks were below regulatory thresholds, they exceeded risk management levels typically used in the state of California. For non-cancer health effects from long-term exposures, the risk estimates exceeded the U.S. Environmental Protection Agency (EPA) hazard index of 1.0 for three health effect categories: neurological; eye, nose and throat; and respiratory. In addition, the combined exposure to four cancer-causing substances (benzene, ethylbenzene, formaldehyde and acetaldehyde) reached the EPA risk management level of 1 excess cancer per 10,000 people exposed and exceeded the California EPA Proposition 65 risk threshold of 1 excess cancer per 100,000.[39‡] The study did not calculate health risks at distances of less than 500 feet because Colorado requires a 500-foot minimum buffer distance between oil and gas activities and buildings. These findings suggest that mitigation controls may be needed in addition to the existing setback distance in order to reduce the potential health risks from air emissions from local oil and gas operations.[40,41]

Many of the project-specific EIRs for oil and gas development reviewed for this report predicted significant impacts from not only the drilling of new wells but also from construction, traffic, and other activities related to the project. The EIRs also include project-specific mitigation measures or alternatives that could be used to reduce or eliminate toxic air emissions associated with the project. Examples of mitigation measures included requiring emission controls for operational equipment and vehicles, as well as air monitoring to evaluate the effectiveness of those measures.

The Air Toxics "Hot Spots" Information and Assessment Act enacted in California in 1987 (Assembly Bill 2588) requires Health Risk Assessments for "high-priority" facilities that emit toxic air pollutants, including prioritized oil and gas facilities. SCAQMD prioritizes facilities based on toxicity and volume of hazardous materials released from a facility, as well as the proximity of a facility to sensitive populations such as residences, schools, daycare centers and hospitals.[42] However, not all oil and gas development projects are required to conduct a Health Risk Assessment.

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[*] For non-cancer health effects, the health-based reference value is the exposure level below which health effects are not expected to occur, even for potentially sensitive people in the general population.
[†] For cancer causing substances, there are no safe levels of exposure.
[‡] CDPHE reported the combined cancer risk estimate was 9.7×10^{-5}.

Odors

Hydrogen sulfide (H_2S) occurs naturally in crude petroleum and natural gas and is also a by-product of desulfurization processes in oil and gas industries. It is an odor with a "rotten-egg" smell that may be associated with some oil fields in the Los Angeles Basin. Hydrogen sulfide has a low odor threshold, defined as the lowest concentration perceivable by human smell, ranging 0.008 to 0.13 parts per million (ppm).[43] Detection of odors due to hydrogen sulfide varies considerably in the human population and can lead to symptoms such as headaches and nausea, as well as eye, nose, throat and respiratory irritation, in addition to being able to adversely impact overall quality of life and wellbeing. California Environmental Protection Agency (CalEPA) has adopted a threshold of 0.008 ppm for long-term exposure to hydrogen sulfide.[44]

Odors may also be the first indication of accumulation of gases which may reach hazardous levels in confined spaces if left unchecked. Historical case studies serve as reminders of the potential for hydrogen sulfide gases to migrate to the surface. For example, the Edward R. Roybal Learning Center (formerly known as the Belmont Learning Center) was developed over part of what was once the Los Angeles City Oil Field and required extensive monitoring and mitigation for hydrogen sulfide from gas migration.[45]

The Oil and Gas Strike Team reported hydrogen sulfide levels are absent or low at the 15 facilities in unincorporated Los Angeles County, based on available data; and no odor complaints were reported for those facilities in SCAQMD's database. [8] The presence of hydrogen sulfide seems to vary depending on specific oil field conditions, and more environmental data are needed to characterize the extent of hydrogen sulfide in the Los Angeles Basin. Depending on the type of operations and proximity of people nearby, some EIRs and HIAs reviewed for this report concluded that odor events would lead to significant and unavoidable impacts to residents living nearby while others provided evidence that odor mitigation plans would alleviate odor impacts for nearby residents.

Noise

There are a number of activities associated with oil and gas that can increase noise levels. The Los Angeles County Code (Section 12.08.390) exempts oil and gas operations from exterior noise standards during routine maintenance work and drilling activities. The primary sources of noise evaluated in the seven EIRs were construction machinery and drilling operations. Specifically, workover of oil and gas wells and well pump operation could elevate noise levels above exterior noise standards. Additionally, health impacts from noise can result from exposure to pure tones and low frequency noise sources.[§]

[§] Pure tones result when a flare burns residual gas into the atmosphere, or when metal-to-metal contact occurs in oil equipment. Low-frequency noise is associated with power-generating plants. Processes within odorization plants can induce pure tones.

An extensive noise study conducted by Kern County estimated setback distances based on noise of 1,550 feet during well advance and 930 feet during well workover activities.[46] The majority of the EIRs found noise to be a significant impact that could be effectively mitigated. Furthermore, projects subject to the Los Angeles County zoning ordinance and permitted by the Department of Regional Planning with noise impacts are required to be mitigated.

Vibration

Along with noise, drilling operations may increase vibration for nearby residents. Various equipment used in oil and gas drilling operations have established vibration levels, which inform the EIRs and HIAs that have been conducted. While some EIRs reported less than significant impacts from vibrations, vibrations associated with certain oil and gas operations can have significant environmental and structural impacts.

Hazardous Materials

Chemicals are routinely used as part of oil and gas operations for a variety of processes, including corrosion control, wellbore cleanouts, repairs, and cementing of well casing. Hazardous chemicals may be added to drilling fluids and drilling muds, and used for enhanced oil recovery (e.g. hydraulic fracturing) as well as routine well maintenance activities (e.g. maintenance acidizing, gravel packing, and well drilling). In a comprehensive assessment of the SCAQMD database of chemicals used for routine oil and gas activities and those used for well stimulation in the Southern California, Stringfellow et al. inventoried the most frequently used chemicals – solvents, petroleum products, salts and strong acids.[10] Notably, hydrochloric acid and hydrofluoric acid (with concentrations of 0-15% and 0-3%, respectively) were used extensively in large quantities for routine activities such as acid cleaning for well maintenance. For each routine maintenance activity, the average mass of hydrochloric acid and hydrofluoric acid used was 1,791 and 161 kg, respectively. Stringfellow et al. concluded that there is substantial overlap between chemicals used for routine oil and gas activities and those used in hydraulic fracturing in the Southern California.

In the event of an accidental release, some of these chemicals used for routine maintenance activities could cause immediate environmental and health impacts. For example, acute symptoms of exposure to strong acids include irritation to the eyes, skin, nose and throat; pulmonary edema; eye and skin burns; rhinitis; and bronchitis. There is a lack of hazard information on the utilization of many chemicals in oil and gas operations, thus preventing emergency personnel and regulatory agencies from understanding the full scope of potential health and safety risks. The toxicity of known chemicals, combined with the gaps in health information on other chemicals, underscores the importance of robust emergency management plans to prepare for or prevent significant casualties if a large-scale incident were to occur.

Oil and Gas Seepage

Oil and gas seepage has the potential to impact many environmental concerns, including subsidence, seismic activity, releases and explosions, and aquifer contamination. Continued production and leaking oil wells can result in near-surface gas accumulation, which may pose an explosive hazard. Oil and gas seepages have been documented across Los Angeles City, including the Fairfax area, south La Brea, Playa del Rey, Santa Fe Springs, and Echo Park. In 1985, an explosion in the Fairfax area demolished a Ross department store as a result of subsurface gas accumulation. One report links the gas accumulation to a nearby oil well;[45] however, there is still debate as to the root cause of the explosion.

Poor well completion and/or abandonment procedures can result in oil and gas leaks that negatively impact air quality in residential neighborhoods (see DPH neighborhood health investigation in Section IV). A comprehensive study of 41,000 conventional and unconventional oil and gas wells in Pennsylvania raises the issue of compromised structural integrity of well casing and cement as one mechanism likely leading to gas migration into the air (i.e. fugitive emissions) or underground drinking water sources (i.e. aquafer contamination).[47]

Summary

Many of the EIRs and HIAs for oil and gas development projects predicted significant impacts from air emissions, odors, noise, vibration and safety hazards; and provided site-specific mitigation measures to try to reduce or eliminate those impacts. In particular, effective mitigation measures were designed to substantially reduce or eliminate impacts from air emissions and noise. Depending on operational and environmental conditions, odor impacts from routine operations and/or emergency events may not be possible to mitigate with currently available measures. Community Safety Plans and enhanced Emergency Response Plans should be developed to address the significant possible safety hazards associated with oil and gas activities and to prepare for leaks, seepage and other potential disasters. Alongside preparedness plans and mitigation measures, environmental monitoring that is both comprehensive and continuous will allow operators and regulatory agencies to develop evidence-based strategies to protect public health.

IV. Neighborhood Health Investigations

A. AllenCo Energy Facility

On October 18, 2013, the SCAQMD asked DPH to assess whether conditions at the AllenCo Energy Facility (AllenCo), located at 814 W. 23rd Street in the City of Los Angeles, were adversely affecting the health of nearby residents in the University Park Community of South Los Angeles.

According to regulatory records, the AllenCo facility appeared to have operated in "general compliance" with permit conditions; however, a comprehensive EIR or HIA was not required to establish permit conditions. Odor and health complaints from the public persisted over several years. Health complaints included headaches, nausea, as well as symptoms associated with irritation to the eyes, nose, throat and airways. Symptoms were recurrent and seemed to arise in conjunction with odor complaints.

The AllenCo facility consisted of seven operational oil production wells at 814 W. 23rd Street, with an additional 14 wells at several other nearby locations. An active well at the facility is located 60 feet from multi-unit housing in the adjacent community, and its property shares borders with a local high school and a college dormitory.

The AllenCo facility was in "general compliance," meaning that it complied with the terms of the regulating agencies and the petroleum-based compounds emitted at the facility appeared to be well below levels that would lead to long-term systemic health effects. However, intermittent exposure to low level emissions can cause recurrent short-term health effects with symptoms consistent with those reported by neighboring residents.

Conclusion

The DPH neighborhood health investigation concluded that the emissions from the AllenCo oil operations at the facility were associated with the reported health effects by community members and that conditions were unlikely to resolve without the company modifying or curtailing facility operations. Recommendations were made to the regulatory agencies regarding a facility-wide audit to identify sources of equipment and process-related emissions within the facility. One further recommendation was that regulatory agencies should continue to explore opportunities to further mitigate emissions using the best available technology when feasible at oil production facilities situated in urban areas with the goal of minimizing odor emissions.

A study of households near AllenCo found that many residents were not aware of their proximity to the oil production site (45.8%) and the majority would not know how to report a complaint to SCAQMD or other agency (78.5%).[48] Given the lack of awareness and the duration of odor complaints, protocols to improve interagency coordination and data sharing are needed to promptly identify potential issues and address community concerns.

B. Firmin Street

On July 15, 2016, the California Department of Conservation, Division of Oil, Gas, and Geothermal Resources (DOGGR) in cooperation with the City of Los Angeles, began working to permanently plug and abandon two orphan wells located at 323 and 324 Firmin Street, in the neighborhood of Echo Park, Los Angeles. Both orphan wells were located in the front yards of residential properties. The permanent plugging and abandonment process required operation of large, industrial stationary equipment (e.g. workover rigs and cement pumps) as well as mobile equipment (e.g. power rigs and heavy trucks) within feet of residential homes.

On July 30, 2016, the City of Los Angeles referred to DPH a resident who was experiencing acute symptoms during the plugging and abandonment operations at the two orphan wells. The resident identified concerns regarding “rotten egg” and strong petroleum odors, as well as the appearance of black soot-like dust inside her home and on her property during well plugging activities. DPH officials conducted a neighborhood health investigation to observe plugging operations at the orphan wells, to document environmental conditions, and to conduct interviews with nearby residents.

During the DPH investigation, health and safety hazards (e.g. particulate matter and noise from well workover activities) were observed in proximity to at least seven households, including the complainant. Residents included young children and elderly people, as well as a high school located two blocks away. The majority of households that reported symptoms to DPH had pre-existing chronic health conditions. Additionally, residents reported that “rotten egg” odors had been intermittent in their neighborhood for many years.

DPH was advised that outdoor air was monitored by the SCAQMD, which reported that levels of methane and hydrogen sulfide did not pose a health threat. However, noise, odor, dust, and diesel emissions associated with the permanent plugging and abandonment procedures taking place in proximity to homes did pose risks to the community, including safety hazards, as well as short-term and long-term health effects.

Short-term Health Impacts

During DPH’s neighborhood health investigation, all seven interviewed households reported short-term health symptoms that began when work started to permanently plug and abandon the two orphan wells on Firmin Street. In some cases, residents reported that their medical providers prescribed new medication as a result of worsened respiratory conditions. The most common symptoms included headaches, nausea, vomiting, eye and throat irritation, skin rashes, and exacerbation of pre-existing respiratory conditions such as asthma. These complaints are consistent with exposure to strong petroleum odors, increased levels of airborne particulate matter, or direct contact with crude oil.

Additionally, DPH heard loud rig drilling noise at the front porches of nearby residential properties. Conversations were inaudible at times during resident interviews. Some residents reported extended work hours on the orphan wells, such as beginning at 6:30am or ending at 9:00pm without prior public notification, or working on weekends. One resident who worked night shifts had difficulty sleeping during the day.

Long-term Health Risks

During the neighborhood health investigation of the two orphan wells, DPH also identified the presence of a third well (Patel 2) located at 314 Firmin Street in the backyard of two residential properties that was considered idle, meaning that it is not currently being used for oil production but it has yet to be determined if the operator will reactivate it or if it needs to be permanently plugged and abandoned. DOGGR issued a notice of violation to the operator of Patel 2 on June 21, 2016 for eight violations, including lack of proper signage, unremediated spills and leaks, and lack of fencing and floor grating to prevent trip and fall safety hazards to people and animals.

The noncompliant Patel 2 idle well poses an ongoing source of direct exposure to petroleum, particularly to children or pets who may inadvertently come into contact with it and also presents long-term health risks to residents from fugitive emissions, such as increased risk of nervous system problems and reproductive system effects. Unfortunately, the violations DOGGR made to the operator for Patel 2 a year prior were not enough to ensure public health and safety, and on November 4, 2017 there was another hazardous release of crude oil from a pipe connecting this well to the tank farm.[49]

Conclusion

DPH concluded that exposure to dust, odor, noise, and vehicle exhaust emissions from the permanent plugging and abandonment of orphan wells led to significant symptoms in some residents, and these symptoms persisted until the operations were complete. In order to protect public health, DPH recommended implementing additional safety measures and offering temporary relocation assistance to affected residents in the area. Based on DPH recommendations, DOGGR provided timely and regular project updates to the residents through face-to-face communications in order to disseminate pertinent information such as project timelines, health resources, and planned changes to resident access.

V. Consultations with Other Jurisdictions

In California, DOGGR has jurisdiction over subsurface oil and gas activities, including drilling, operation, maintenance, and abandonment of oil and gas wells. Los Angeles County officials may regulate zoning and land use to reduce impacts from surface operations on the surrounding communities. Current Los Angeles County Zoning Ordinance regulations require a Conditional Use Permit for the drilling of oil and gas wells on certain land use zones within 300 feet from sensitive land uses such as residential zones, public schools or parks.[9] However, the requirement does not apply to oil and gas wells operating prior to the adoption of the ordinance and it does not establish similar requirements for the development of sensitive land uses such as residences near existing oil and gas wells (Timothy Stapleton, Los Angeles County Department of Regional Planning, personal communication, November 15, 2017).

Some cities within Los Angeles County have ordinances established to regulate oil and gas drilling within their jurisdictions. For example, the City of Carson established a 750-foot setback distance after conducting a review of other setback distances and potential environmental impacts.[50] Within Los Angeles County, the Baldwin Hills Community Standard District was established to regulate oil and gas activities in the Inglewood Oil Field.[6] Wells in other parts of the county are not subject to the same level of oversight, and operate with various permit conditions and regulations depending on the project.[7]

In order to better understand oil and gas ordinances adopted by other jurisdictions, DPH consulted with ten jurisdictions that have established requirements, such as setback distances, in order to limit the potential negative health and safety impacts of oil and gas production. These ten jurisdictions have various setback requirements, ranging from 210 to 1,500 feet (Table 1).

Table 1. Summary of Setback Distances for New Wells in Other Jurisdictions**

State	Jurisdiction	Year Adopted	Setback Distance (feet)	Setback Target
California	City of Carson	2015	750	Housing, schools, hospitals
California	Kern County	2015	210	Housing, schools, hospitals
Colorado	State	2013	500	Housing
Maryland	State	2016	1,000	Housing, schools, faith institutions
			2,000	Private drinking water well
New Mexico	Santa Fe County	2008	750	Housing, schools
			1,000	Groundwater and surface water resources
Oklahoma	Oklahoma City	2015	300	Housing, fresh water well
			600	Faith institutions
Texas	City of Arlington	2011	200	Fresh water well
			600	Housing, schools, faith institutions, hospitals
Texas	City of Dallas	2013	1,500	Housing, schools, faith institutions
Texas	City of Flower Mound	2011	1,500	Housing, schools, faith institutions, hospitals, existing water wells
Texas	City of Fort Worth	2010	200	Fresh water well
			600	Housing, schools, faith institutions, hospitals

** The setback distances are for protected or sensitive land use areas defined as: housing, schools, faith institutions, hospitals, and water wells (and other sources of water).
Other jurisdictions not included in the table may have differing setback distances (e.g. Huntington Beach, Long Beach, and Signal Hill have setback distances of 300 feet).

When DPH asked each jurisdiction about the supporting rationale and available evidence for each of the setback distances, there were two key themes:

- Flammability and other safety concerns (e.g. explosions) related to minimum distance between industrial operations and structures, based on Fire Code.
- Air quality impacts, with supporting data from both direct measurements and modeled estimates. In a few cases, jurisdictions have established extensive monitoring networks to estimate and enforce the air emissions released by oil and gas activities (Fort Worth and Flower Mound, Texas).

When further asked about the approach used to develop the setback distances, jurisdictions responded with a wide variety of different processes. Some jurisdictions formed a task force with academic researchers, oil industry representatives and other independent experts, while others focused on community-based participatory processes to reach a consensus. Jurisdictions sometimes took a systematic research-based approach by conducting lengthy and comprehensive assessments, looked to other jurisdictions for guidance, or chose distances reflecting information gaps on chemicals utilized, air and fugitive emissions, and impacts to public health for oil and gas sites within their purview.

Two published review studies of setback distances for oil and gas activities suggest that setback distances alone may not be enough to protect public health from unconventional oil and gas operations (e.g. hydraulic fracturing). One study surveyed expert scientists, public health professionals and medical professionals regarding setback distances, and found that 89% of participants agreed that a minimum safe distance to unconventional oil and gas operations was a quarter of a mile (1,320 feet).[51] Another study reviewed whether setback distances from hydraulic fracturing ranging from 150 to 1,500 feet are protective from air pollution, blowouts or other safety risks and concluded that a combination of a reasonable setback distance with mitigation process controls is the best method for reducing the potential threats to public health.[52]

The setback distances adopted by various jurisdictions apply to future development of oil and gas sites such as drilling new wells or through land use permitting processes. The setback requirements typically do not apply to existing oil and gas wells that are operating prior to the adoption of the ordinance. Some jurisdictions have additionally established requirements for mitigation measures when operations are less than the specified distance in order to reduce public health and safety risks. For example, Kern County's ordinance requires mitigation to reduce potential noise impacts from certain oil and gas activities. After conducting an extensive noise study in an environmental impact report, Kern County found that noise impacts from certain operational activities were significant unless mitigated (e.g. 1,550 feet for well advancement, 930 feet for well workovers).[46] Another example is the City of Carson's Oil and Gas Ordinance that requires mitigation to reduce noise impacts from facilities within 1,000 feet of sensitive land use zones, and requires an odor minimization plan for facilities within 1,500 feet of sensitive land use zones.[50]

Setback distances combined with appropriate mitigation measures can reduce many of the public health and safety risks associated with oil and gas operations for new and existing oil and gas operations in proximity to sensitive populations. An assessment of each oil and gas facility is necessary to identify current distances from existing operations to sensitive land uses and whether current mitigation measures sufficiently address the potential safety and environmental hazards and are protective of public health. Expanded monitoring of oil and gas operations will enable prudent guidance for reducing the health and safety risks from toxic air emissions, gas migration, subsidence, soil and groundwater contamination, and aging infrastructure. In addition, zoning requirements should restrict future development of sensitive land uses close to existing oil and gas operations in order to further protect public health.

VI. Conclusion

Overall, epidemiological studies have found limited associations between certain kinds of adverse health effects and living near oil and gas operations; however, quality exposure data to accurately assess risk is lacking. The vast majority of studies have not assessed people's exposure over long periods of time and highlight the need for future research to include studies with large sample sizes and more precise measurement of an individual's exposure to a myriad of chemicals that have potential to adversely affect health. The epidemiological literature is unable to conclude at this time whether or not living, working, or going to school near oil and gas facilities is associated with long-term negative health impacts.

In addition to epidemiological studies, this report includes evidence from EIRs and HIAs of oil and gas operations primarily in California. Such reports and assessments help fill some information gaps from available epidemiological studies. Evidence from numerous potential impact areas ranging from air pollution to catastrophic releases, compels the need for public health intervention to protect against potential negative environmental and health impacts from oil and gas operations located in densely populated urban areas. Many EIRs proposed mitigation measures to reduce potential risks and hazards. In the absence of such controls, or if the impacts are unable to be mitigated (e.g. odors), potential public health risks are likely to remain, and may be particularly heightened for vulnerable populations such as young children. Depending on land use, some environmental and site conditions may be incompatible with oil and gas operations, regardless of mitigation controls.

The oil and gas development projects described in the reviewed EIRs and HIAs have assessed environmental and health hazards, and in many cases propose mitigation measures for reducing the identified risks. However, such assessments are not required for every operating oil and gas facility and for some facilities, health and safety risks are identified only after residents' complaints gain the attention of regulators and other agencies. As observed during DPH's two neighborhood health investigations in response to health complaints from residents near oil and gas operations (refer to Section IV for more information), health effects may occur with the detection of odor emissions, even when those emissions are within regional air quality standards. Routine occurrences of odor and noise emissions from operations can lead to recurrent short-term health problems, which may negatively impact the long-term wellbeing and quality of life of nearby residents. Conventional risk assessment methodologies can be limited in their ability to address these factors and to anticipate other kinds of complex health and quality-of-life consequences. In addition, the lack of monitoring data to estimate potential exposures to such emissions from oil and gas operations creates further uncertainty regarding long-term health impacts to nearby residents.

DPH's experience with health complaints from a neighborhood health investigation involving the permanent plugging and abandonment of two orphan wells, as well as one idle well located nearby, highlighted several issues with old, abandoned wells that are found across Los Angeles County:

- Orphan wells are often improperly abandoned, or left idle, which may result in communities being impacted by hydrogen sulfide and petroleum odors.
- Workover rig equipment and related abandonment operations produce dust, odor, and noise that may lead to symptoms among people living nearby.
- Mitigation measures were successfully implemented to reduce the health and safety risks identified by DPH.
- Residents were empowered to take health protective measures through enhanced communication.

Aging oil and gas infrastructure in Los Angeles County, not only at abandoned wells, but also at active wells, pipelines, and associated infrastructure, raises an important public health concern. Regulatory agencies and operators should explore opportunities to utilize the best available technology at oil production facilities in order to prevent public health impacts.

DPH identified a number of gaps in information, highlighting the need for further monitoring and health research. Primarily, the following are needed to more completely estimate the potential health risks from oil and gas operations in Los Angeles County: 1) air monitoring data to estimate potential exposures to chemical emissions from oil and gas operations, 2) proactive odor surveillance systems to identify hydrogen sulfide releases from active, idle, and abandoned wells, and 3) toxicity testing of chemicals and chemical mixtures used in oil and gas operations. In the absence of more robust exposure and health data, it is not possible to reliably quantify potential health risks.

Based on the available scientific evidence, other local and state agencies have established setback distances ranging from 210 to 1,500 feet in order to protect public health and safety amidst oil and gas operations; these setbacks were based primarily on the potential for safety concerns and air quality impacts. In addition to setback distances, particularly in cases of existing oil and gas operations within the minimum setback, alternative measures (e.g. engineering controls, monitoring, closure) combined with monitoring are necessary to protect the health and safety of the surrounding communities.

VII. Next Steps

The potential for adverse health effects from exposure to chemicals found at oil and gas facilities, combined with the need for more research and monitoring, warrants precautions in policy-making. The two DPH neighborhood health investigations suggest the need for immediate actions to protect health at oil and gas facilities located immediately adjacent to sensitive populations. Oil and gas facilities across the Los Angeles Basin would benefit from periodic review to assess the effectiveness of existing mitigation measures, monitoring requirements, and impacts on the surrounding community.

DPH has determined through its literature review, discussions with other jurisdictions, and neighborhood health investigations that there is sufficient evidence to provide health-based guidance in five areas – setback distances, air monitoring, preventative maintenance and testing, community safety planning, and emergency response planning. DPH will collaborate with County partners, enforcement agencies and interested stakeholders to further inform the development of health-protective policies and regulations.

The findings in this report support the recommendations set forth by the interagency Oil and Gas Strike Team.[8] The final report by the Oil and Gas Strike Team recommended that Los Angeles County further evaluate the following key areas:

- Removal of "by right" permitting (as required by the Board Motion)[7]
- Setback distances
- Well stimulation techniques (to reflect state regulations)
- Air quality and odor monitoring
- Transportation of chemicals in residential areas
- Pipeline monitoring and leak detection
- Abandonment of long idle wells
- Review of Emergency Response Plans
- Community communication

1) Setback Distances

Los Angeles County and local jurisdictions within the County should expand the minimum setback distance beyond 300 feet, as currently specified in local zoning code, and apply these requirements to both the siting of new wells and to the development of sensitive land uses near existing operations. It is important to note that a setback distance is not an absolute measure of health protection and additional mitigation measures must also be considered. For existing oil and gas operations, a site-specific assessment at each facility throughout the County is necessary to identify current distances to sensitive land uses and other site characteristics that can be used to inform whether further mitigation measures are warranted to reduce potential public health and safety risks.

The table below summarizes various setback distances, mitigation targets, remaining hazards and whether additional mitigation measures could further reduce potential adverse impacts (Table 2). This table is based on information compiled from scientific publications,[13,37,51,52] environmental impact assessments,[27-33] other environmental studies,[10,16,20,34,35,36,46] and experiences in other jurisdictions.

Table 2. Review of Key Public Health and Safety Hazards and Setback Distance Guidance

Setback Distance	***Air Quality***	***Noise***	***Odors***	***Fires, Explosions, and Other Emergencies***	***Additional Mitigation and Assessment Notes***
300 feet					Some health and safety impacts may still be unavoidable regardless of additional mitigation.
600 feet	✓				Additional mitigation and assessment would likely be needed to avoid most impacts. Odors may be unavoidable, regardless of mitigation. Air monitoring is advised.
1,000 feet	✓	✓			Additional mitigation and assessment may be needed to avoid noise impacts during certain operations, e.g. well advancement. Odors may be unavoidable in loss of containment events, regardless of additional mitigation.
1,500 feet	✓	✓	✓		Additional mitigation not likely to be needed. Some uncertainty remains due to gaps in long-term health and exposure data.

✓ Represents the distance at which the impact is likely mitigated

2) Air Monitoring

In coordination with the California Air Resources Board (CARB) and the South Coast Air Quality Management District (SCAQMD), Los Angeles County should require the operators of facilities within urban areas of the County to implement continuous air monitoring systems around oil and gas operations to:

- Measure air pollutants released by oil and gas operations;
- Ensure oil and gas sites comply with environmental regulations;
- Evaluate the impact of releases from oil and gas sites on surrounding neighborhoods; and
- Monitor setbacks for these sites regularly, based on air monitoring and emerging science, and revise setback distances and/or other mitigation requirements when necessary to protect public health.

It should be noted that SCAQMD has imposed some requirements related to public notification and monitoring, but only after concerns are identified at a particular oil and gas operation, such as odor complaints. Current monitoring and enforcement activities can be sporadic, and it is difficult to understand long-term exposure risks for people living near oil and gas operations in the absence of continuous monitoring. To better characterize air quality in communities near oil and gas operations, SCAQMD completed a fenceline monitoring study (refer to Section III for more information) and CARB launched the Study of Neighborhood Air near Petroleum Sources (SNAPS); results from these efforts should be used to inform air monitoring policies.

3) Preventative Testing and Monitoring

A variety of state and federal regulations require routine inspections, maintenance, testing and leak detection systems for oil and gas facilities; however, local oversight of these regulations is limited. Optimal local oversight would enhance monitoring for public health and safety risks associated with aging infrastructure, and should include a local auditing and certification process, streamlined coordination, and data sharing among agencies. A local auditing program would confirm that operators are complying with federal, state and local regulations.

4) Community Safety Plan

Operators should prepare and make available to the public a comprehensive Community Safety Plan, in coordination with City and County departments, including Fire, Building and Safety, and Law Enforcement. These plans should include information on hazardous chemicals stored onsite; air emission monitoring efforts; and health-based exposure thresholds to identify the need for additional mitigation. For operations to plug wells permanently or to perform well maintenance, the responsible party should also prepare and implement a Community Safety Plan. The Community Safety Plan should facilitate communication and input from local stakeholders, and be submitted to DPH for review and approval. The Plan should include protocols and procedures for immediate notification to the County Health Officer in the event of odor or health complaints.

5) Emergency Preparedness Plan

Operators should maintain enhanced Emergency Preparedness Plans that account for proximity to sensitive land use. These plans must include communication procedures to immediately notify local government agencies of any emergencies, such as spills or other releases.

To further inform health-protective policies and regulations, DPH will collaborate with County partners, local and state enforcement agencies, and interested stakeholders. DPH recommends site-specific assessments at existing oil and gas operations near sensitive land use to determine the appropriate combination of setback distance and additional mitigation measures, as well as the extent to which these measures are sufficient to protect public health.

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Glossary of Selected Terms

Casing is a metal tube used during drilling an oil well in combination with cement to sequentially stabilize recently drilled formation as well as providing strong upper foundation and isolating separate zones.

Drilling is to dig or bore in the earth for the purpose of exploring for, developing, or producing oil, gas, or other hydrocarbons, or for the purpose of injecting water, steam, or any other fluid or substance into the earth.

Environmental Impact Report (EIR) is an informational document which provides public agencies and the general public with detailed information about the effect that a proposed project is likely to have on the environment. The EIR also lists the ways in which these environmental effects might be minimized and whether there are any alternatives to such a project.

Epidemiology is the study of the distribution and determinants of health-related states or events in specified populations, and the application of this study to the control of health problems.

Frack-pack is commonly used to re-direct the flow to prevent sand from entering a well and to bypass damaged zones near a well. As opposed to hydraulic fracturing intended to open permeable fracture pathways in unconventional reservoirs to enable oil or gas production, frac-packs are employed to deal with formation damage around a production well and/or sand production into the well.

Gravel pack is a method of controlling sand production that involves installation of a cylindrical metal screen in a production zone of a well in with the annulus between the screen and the casing (or formation if not cased) is filled with fluid slurry containing gravel. Gravel pack pressures are kept below fracture pressures.

Grey literature consists of materials and research produced by organizations outside of the traditional commercial or academic publishing and distribution channels, e.g. reports, working papers, government documents, etc.

Hazard is any biological, chemical, mechanical, environmental, or physical stressor that is reasonably likely to cause harm or damage to humans, other organisms, the environment, and/or engineered systems in the absence of control.

Health Risk Assessment (HRA) is a technical study that evaluates how toxic emissions are released from a facility, how they disperse throughout the community, and the potential for those toxic pollutants to impact human health.

Hydraulic fracturing is a process to produce fractures in the rock formation that stimulates the flow of natural gas or oil, increasing the volumes that can be recovered. Fractures are created by pumping large quantities of fluids at high pressure down a wellbore and into the target rock formation.

Idle well is any that has not been used for the production of oil and gas, the production of water for the purposes of enhanced oil recovery or reservoir pressure management, or injection for a period of 24 consecutive months.

Impact (or consequence) is the particular harm, loss, or damage that is experienced if the risk-based scenario occurs.

Mitigation is ongoing and sustained action to reduce the probability of, or lessen the impact of, an adverse incident.

Orphan is a well, pipeline, facility or associated site which has been investigated and confirmed as not having any legally responsible and/or financially able party to deal with its abandonment and reclamation responsibilities.

Risk incorporates the likelihood that a given hazard plays out in a scenario that causes a particular harm, loss, or damage. In quantitative risk assessments, risk is calculated as likelihood multiplied by impact.

Unconventional oil and gas operations allow for drilling down, drilling horizontally, and/or fracking to allow oil and gas to be explored, developed and produced. This compares to conventional processes that use the natural pressure of the wells, or water/gas injection, and pumping or compression operations to extract oil and gas resources.

Well is any oil or gas well or well drilled for the discovery of oil or gas; any well on lands producing or reasonably presumed to contain oil or gas; any well drilled for the purpose of injecting fluids or gas for stimulating oil or gas recovery, repressuring or pressure maintenance of oil or gas reservoirs, or disposing of waste fluids from an oil or gas field; any well used to inject or withdraw gas from an underground storage facility; or any well drilled within or adjacent to an oil or gas pool for the purpose of obtaining water to be used in production stimulation or repressuring operations.

Well stimulation treatment means a treatment of a well designed to enhance oil and gas production or recovery by increasing the permeability of the formation. Examples of well stimulation treatments include hydraulic fracturing, acid fracturing, and acid matrix stimulation.

Workover means to perform one or more of a variety of remedial operations on a producing well to try to increase production, e.g. deepening, plugging back, pulling and resetting liners, squeeze cementing, etc.

Appendix A – Public Health Screening Assessment

Facility:			
Issue	**Checklist Code**	**Determinations Contributing to Higher Degree of Public Health and Safety Impact Ranking**	**Findings**
Public Health Risk			
High Priority Risk Items			
Land Use and Zoning		Proximity to residential or other public receptor locations (multiple receptors within 300’)	
Hydrogen Sulfide		High H2S levels (>500 ppm within process systems)	
Wellhead Pressures		High well head pressures (>250 psig)	
Historical Activities		High levels of drilling onsite (> 4/year) contributing to noise, traffic and accident risk	
Risk Contributing Items			
Public Health			
Sensitive Populations and children		Proximity to residential areas or other sensitive populations (e.g. schools, hospitals, senior communities, homeless)	
Socioeconomic Status and health disparities	CalEnviroscreen	Surrounding community faces socioeconomic or health disparities and challenges	
Environmental			
General Facility Operations			
History		Older facilities (> 25 years)	
Gas treatment		The use of gas treatment equipment onsite	
Steam recovery		The use of steam generation onsite	
Gas pipeline pressure		High gas pipeline pressures	
General/Other			
PRV to atmosphere	G.2-3	Venting to atmosphere	
Flares availability	G.8	Flares not available	
Noise			
Sound proofing for drilling closer than 500’	N.2	No soundproofing for facilities within 500’	
Pure tones		Pure tones or low frequency	
Deliveries time limits	N.4	No time limits on deliveries	

Facility:			
Issue	**Checklist Code**	**Determinations Contributing to Higher Degree of Public Health and Safety Impact Ranking**	**Findings**
Aesthetics/Infrastructure			
Derricks removed, unused equipment	FI.2, FI.3, FW.4	Presence of older equipment	
Sumps: hazard to people, screening	SM.4, SM.6, SM.10, SM.11	Hazardous, no screening on top, electrical/trip fall hazards	
Air Quality			
Air Toxics		Part of the AQMD AB2588 program	
Monitoring systems within 1500' of residences	AQ.7	No monitoring systems	
Safety			
Drilling			
Drill sites 75' from boundary, 100' from buildings, 300' of a residence	D.2	Closer than prescribed distances	
Drill sites within 500' of a residence	D.5, N.2, N.3	Closer than 500' and not using sound proofing methods	
Setbacks			
Critical wells	SB.3, SB.4	Critical well and free-flowing production	
Wells 20' highway, 75' street, 100' building, 300' school, 25' of ignition sources?	SB.6, SB.7, SB.8, SB.9, SB.10	Closer than setback distances or close to powerlines due to rig height	
Gas Pipelines			
Inspection history	PL.1	No internal inspection history	
Alarms and shutdown	PL.5 – PL.8	No procedures or systems, manual shutdown, no 24 hr attendance	
Pipeline signs and labeling		No markings or warning signs posted along visible pipelines going through private driveways, parking spaces, other traffic roads	
Fire			
Sufficient clearance	F.3	Poor fire preparation	
Fire water capabilities	F.4 – F.5	Inadequate fire water	
Hazardous Materials	HM.8	Transportation of highly hazardous materials through residential areas	
ERP: Drills	ER.2 - ER.3	Inadequate ERP and drills	
Security: Fencing	S.1-S.5	Inadequate fencing	

Facility:			
Issue	**Checklist Code**	**Determinations Contributing to Higher Degree of Public Health and Safety Impact Ranking**	**Findings**
Documentation			
AQMD 1173 reports: odors, GHG, toxics emissions		High numbers of leaking components	
AQMD Odor Complaints		Multiple odor complaints	
AQMD NOV/NTC		Multiple NOV/NTC	
Fire: annual inspection		Inspection report findings	
Public Health: complaints		Multiple complaints	
DOGGR: inspection reports		Inspection report findings	
ERP		ERP not available or inadequate	
Wells/facilities within 100' feet of waterways	SB.3	Located closer than 100' to waterways	
Could a release affect nearby creeks?	SC.5	Could affect nearby creeks	
Adequate secondary containment?	SC.2 – SC.5	Lack of secondary containment/berms	
Sufficient onsite spill cleanup and control equipment?	SP.17	Lack of onsite control equipment and personnel responsible for cleanup	
Crude/Emulsion Pipelines: Inspection	PL.1	No internal inspection history	
Crude/Emulsion Pipelines: Alarms and shutdown	PL.5 – PL.8	No procedures or systems, manual shutdown, no 24 hr attendance	
SPCC	SP.1 – SP.21	SPCC inadequate	
Site Contamination Risk			
Does the site history indicate the potential for site contamination?	G.12	Potential history of tank farm or other activity indicating potential for contamination	

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Communication from Public

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Comments for Public Posting:	In response to oil industry comments that drilling operations do not negatively impact public health and the environment, the Center for Biological Diversity offers the following list of studies and articles. There is strong evidentiary support for the City's action. Select studies have been submitted as attachments. This is submission 2 of 2 to stay below file size requirements.

Exhibit 9 of 13 - Okorn 2021. Pod Monitors

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Characterizing methane and total non-methane hydrocarbon levels in Los Angeles communities with oil and gas facilities using air quality monitors

Kristen Okorn [a,*], Amanda Jimenez [b], Ashley Collier-Oxandale [a], Jill Johnston [b], Michael Hannigan [c]

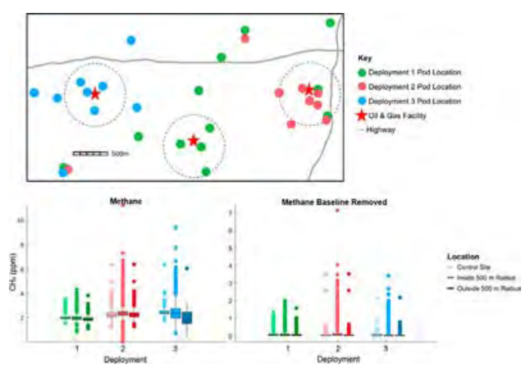
[a] Environmental Engineering, University of Colorado Boulder, Boulder, CO 80309, USA
[b] Preventative Medicine, University of Southern California, Los Angeles, CA 90089, USA
[c] Mechanical Engineering, University of Colorado Boulder, Boulder, CO 80309, USA

HIGHLIGHTS

- Methane emissions were heightened near urban oil and gas facilities.
- An oil and gas facility registered as inactive still appears to emit methane.
- TNMHC spikes may be related to oil and gas activity.
- Natural gas distribution pipelines may also be a source of fugitive methane emissions.
- Sensor networks highlight spatial and temporal differences at neighborhood scale.

GRAPHICAL ABSTRACT

Air quality monitors were deployed in three Los Angeles neighborhoods characterized by oil and gas activity (top); methane levels (bottom left) and baseline removed methane spikes (bottom right) varied based on proximity to oil and gas facilities.



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ABSTRACT

Over the past decade, sensor networks have been proven valuable to assess air quality on highly localized scales. Here we leverage innovative sensors to characterize gaseous pollutants in a complex urban environment and evaluate differences in air quality in three different Los Angeles neighborhoods where oil and gas activity is present. We deployed monitors across urban neighborhoods in South Los Angles adjacent to oil and gas facilities with varying levels of production. Using low-cost sensors built in-house, we measured methane, total non-methane hydrocarbons (TNMHCs), carbon monoxide, and carbon dioxide during three deployment campaigns over four years. The multi-sensor linear regression calibration model developed to quantify methane and TNMHCs offers up to 16% improvement in coefficient of determination and up to a 22% reduction in root mean square error for the most recent dataset as compared to previous models. The deployment results demonstrate that airborne methane concentrations are higher within a 500 m radius of three urban oil and gas facilities, as well as near a natural gas distribution pipeline, likely a result of proximity to sources. While there are numerous additional sources of TNMHCs in complex urban environments, some sites appear to be larger emitters than others. Significant methane emissions were also measured at an idle site, suggesting that fugitive emissions may still occur even if production is ceased. Episodic spikes of both compounds suggested an association with oil and gas activities, demonstrating how sensor networks can be used to elucidate community-scale sources and differences in air quality moving forward.

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* Corresponding author at: 1111 Engineering Dr., Boulder, CO 80309, USA.
E-mail address: Kristen.Okorn@colorado.edu (K. Okorn).

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1. Introduction

1.1. Background and motivation

The growth of oil and gas production in close proximity to communities has driven concerns about impacts to health and the environment. Air pollution associated with oil and gas extraction is a growing concern for public health and environmental quality. Of the chemicals identified in natural gas production, the majority were found to affect the respiratory and gastrointestinal systems as well as sensory organs, and are thought to have long term health effects that have yet to be fully determined (Colburn et al., 2011). Adverse birth outcomes and congenital heart defects have also been associated with pregnant mothers living nearby natural gas and oil development (McKenzie et al., 2014; Tran et al., 2020; Cushing et al., 2020). Numerous studies also suggest that higher rates of immunological deficiencies in adults and children alike may be linked to air pollution from oil and gas activities (Johnston et al., 2019; Yermukhanova et al., 2017; Dey et al., 2015; Kudabayeva et al., 2014; Dahlgren et al., 2007; Willis et al., 2020).

Methane (CH_4) and total non-methane hydrocarbons (TNMHCs) are among the direct and fugitive emissions of highest concern at oil and gas facilities, emanating from production, collection, and processing activities (Allen et al., 2013). Human exposure to high levels of methane can result in nausea, vomiting, headaches, and dizziness (Methane: Your Environment, Your Health, 2017). Although not all TNMHCs are dangerous to human health, many associated with oil and gas activities can pose serious complications when inhaled (Adgate et al., 2014). More generalized symptoms of exposure may include eye irritation, headaches, and worsening instances of asthma. Many of the aromatic hydrocarbons associated with petroleum production, including benzene, have been linked to cases of leukemia, anemia, and non-Hodgkins lymphoma, among other blood disorders (Adgate et al., 2014; Glass et al., 2003; Kirkeleit et al., 2007; Brosselin et al., 2009; White et al., 2009; Goldstein, 2010).

In densely populated urban environments such as Los Angeles, California, the complexity of the surrounding environment also makes determining pollutant sources more difficult. Hopkins et al. concluded that other, often unrepresented, sources of methane in the Los Angeles basin included fugitive emissions from natural gas distribution pipelines, natural gas-fueled vehicles, and waste disposal. In addition, a myriad of industrial centers in the city such as Los Angeles International Airport, downtown, and the Port of Los Angeles were constructed near or directly above major oil fields, making it more difficult to discern anthropogenic sources from their geological counterparts (Hopkins et al., 2016). Nonetheless, the proximity of residents to the epicenters of oil and gas activities raises their exposure risk greatly (McKenzie et al., 2018). In the City of Los Angeles, 70% of active wells operate within 500 m of a home or sensitive land use area, including schools and hospitals. Over half a million people live within this radius of an oil and gas facility in Los Angeles alone (Liberty Hill Foundation, 2015). Understanding air quality impacts at a neighborhood scale is important to assess potential health risks.

1.2. Previous sensor network studies in complex urban environments

Over the past decade, advances in air quality monitoring tools and quantification methods have made it possible to deploy a network of sensors in areas of environmental interest, allowing researchers to discern differences in air quality on much smaller spatial scales. The main roadblocks to broader application of these networks, which tend to be made up of less expensive and therefore less accurate tools, are data quality and detection limit. By distributing multiple sensors in complex urban environments, source attribution is possible. Recently, an air quality monitor network in an Italian city showed elevated levels of CO and NO_x and worsened overall Air Quality Index (AQI) values near heavily trafficked roadways as opposed to smaller roadways (Brienza et al., 2015). Another network of sensors deployed at and around the London Heathrow Airport successfully apportioned higher CO emissions at sites known to be in areas of more direct aircraft emissions, and elevated NO_2 near roadways (Popoola et al., 2018). In the San Francisco Bay area, another monitoring network found the highest mixing ratios of NO, NO_2, and ozone among sensors located near an oil refinery. Similarly, sensors near major roadways with diesel traffic read heightened CO and NO_x emissions (Kim et al., 2019). A particulate matter sensor deployed on a rooftop and near a freeway in Atlanta, Georgia, and later in Hyderabad, India, showed the highest levels of particulate matter in the more polluted city (Hyderabad), with elevated concentrations near a freeway in Atlanta as opposed to on a rooftop (Johnson et al., 2018). Many other previous studies in urban environments similarly have focused on incomplete combustion products such as CO and NO_2. Here we focus on organic gas phase species, specifically methane and total non-methane hydrocarbons. While methane is mainly associated with oil and gas in the area of interest, TNMHCs may emanate from a wide variety of sources.

In southern California, regulatory agencies are deploying suites of sensors to inform residents of air quality on a more localized scale than ever before. South Coast Air Quality Management District (SCAQMD), which encompasses all of Los Angeles County in its jurisdiction, is the government agency responsible for regulating and monitoring emissions in each of the neighborhoods studied (South Coast Air Quality Management District, 2020). SCAQMD deployed approximately 400 commercially available sensors in California communities over a five-year period, evaluating the sensor models used through the Air Quality Sensor Performance Evaluation Center, and making their results and recommendations publicly available (Collier-Oxandale et al., 2020). However, the focus for most of these deployments was on particulate matter as opposed to gas-phase pollutants. In addition, none of these deployments occurred in or around any of the South LA neighborhoods discussed here.

The Hannigan Lab at the University of Colorado Boulder has used the Y-Pod multi-sensor platform ("pods") to examine community-scale air quality in southern California. Approximately 90 km east of Los Angeles, a Y-Pod sensor network was deployed in Riverside, CA in 2015. Researchers distributed the pods across a 200 km^2 area, finding that differences in pollutant levels could be observed on both regional and neighborhood scales (Sadighi et al., 2018).

Y-Pod sensor network studies have taken place directly in Los Angeles. In the fall of 2016, Collier-Oxandale et al. (2018a) began assessing best practices for deploying sensors in complex urban environments, as well as co-location and calibration techniques. Focusing on methane specifically, this work developed methods to filter out improbable sensor and reference readings to improve calibration fits and applications to field data. This prior research also explored sensors' cross-sensitivities to environmental factors as well as other pollutants (e.g., CO), demonstrating that inexpensive volatile organic compound (VOC) sensors can provide useful information on ambient methane in urban environments. (Collier-Oxandale et al., 2018a). This data was also mapped to potential sources and individual air quality events observed throughout the community as reported by residents (Collier-Oxandale et al., 2019).

In the North University Park neighborhood of Los Angeles, Y-Pods were once again deployed throughout the neighborhood to determine air quality differences on a small spatial and temporal scale from November 2016 to June 2017. This also included deploying five pods on different locations on the same building to determine micro-climate effects, suggesting that a myriad of pollutant sources exist in the area even on a highly localized scale in such a densely populated urban environment (Collier-Oxandale et al., 2018b). A diurnal trend of elevated nighttime concentrations and lower daytime concentrations was observed for CH_4 and TNMHCs alike.

Both neighborhoods were chosen as a result of interest from local residents, driven in large part by proximity to urban oil and gas facilities. While oil and gas activities were ongoing in the West Adams neighborhood, active production at the site in North University Park had ceased.

A comparison of sensor readings in each neighborhood showed not only elevated baseline CH_4 concentrations in West Adams, but also more episodic spikes related to oil and gas activities (Shamasunder et al., 2018).

This study is a continuation of the previous studies in oil-adjacent communities in South Los Angeles. The preliminary results of these first two studies are re-examined using a newly developed calibration model that improves sensor fits; this is discussed in Section 3.1. In addition, another active oil facility was monitored throughout 2019, allowing us to examine trends among multiple oil and gas facilities in Los Angeles in a more extensive comparison than has been presented previously. All three facilities draw from the Las Cienagas oil field; their production outputs should have similar chemical properties (South Los Angeles and Southeast Los Angeles Community Draft EIR, 2016). This multi-year study of highly localized gas phase pollutants in Los Angeles, specifically with respect to urban oil drilling, is among the first and most exhaustive of its kind to date.

1.3. Study site demographics

To better characterize the neighborhoods and understand the environmental justice implications of oil and gas activities in these communities, demographics reported by the California Census Bureau are included. The median values of the 3–4 nearest census block groups to each facility, consisting of a few city blocks each, are considered and should provide insight as to which income brackets and racial or ethnic groups are most affected by neighborhood oil and gas activities. Note that this data was collected from 2013 to 2018 by the American Community Survey, California Public Utilities Commission, and the Planning Database.

In the area surrounding the Deployment 1 site, 56% of residents identified as Hispanic or Latino, 29% Black, and 10% Asian. 51% of the community was below 150% of the poverty line. In Deployment 2's neighborhood, 47% identified as Hispanic or Latino and 12% as Black, with 59% below 150% of the poverty line. For the Deployment 3 area, 43% identified as Hispanic/Latino while 47% identified as Black. Similarly to the other two neighborhoods, 54% self-reported as their annual household income being below the 150% poverty line (California Census Bureau, 2020).

In terms of land use, for each deployment most of the area within 500 m of the oil and gas facility is residential and prone to overcrowding. Educational (institutional) and public land use (miscellaneous) claim the next largest proportion of area, including schools, preschools, and libraries. Little to no land is unused in any of these 500 m circles (Liberty Hill Foundation, 2015). This land use data is shown in Fig. 2-C.

2. Methods

2.1. Overview

We followed the sensor field normalization and deployment methodology set forth by previous studies (Piedrahita et al., 2014; Clements et al., 2017; Collier-Oxandale et al., 2018a; Sadighi et al., 2018; Casey et al., 2019; Vikram et al., 2019). The sensor packages used were run adjacent to a high-quality reference monitor, operating under similar conditions to those anticipated during the deployment. The reference data was treated as the standard, and linear regression was used to fit the raw sensor readings to the reference value in parts per million (ppm) for each pollutant. We then deployed our sensor packages in the neighborhoods surrounding three urban oil and gas facilities in South Los Angeles, and applied the calibration models developed previously to the data collected in the field.

2.2. Deployment

We deployed Y-Pods, our embedded sensor packages, in three South Los Angeles neighborhoods from 2016 to 2019. More information on the pod configuration is provided in Section 2.3. Three oil and gas production sites, within three km of each other, were selected as the focal points for three deployments. For each deployment, 4–11 pods were placed within a 500 m radius of the production site, and 2–11 were placed outside the 500 m radius. This included sites adjacent to freeways, a major source of hydrocarbons and combustion products. This also included control sites, that is, areas upwind of oil operations and away from any obvious hydrocarbon sources.

While the number of active wells at the two sites with verified ongoing operations were identical (see Supplemental Table S1), the facility studied in Deployment 3 had the highest oil production while Deployment 1 had the highest gas production in 2017 (California Department of Conservation, 2012). Deployment 2 ceased operations in November 2013 after an Environmental Protection Agency investigation, and was subsequently ordered to pay 1.5 million dollars in penalties and address onsite equipment failures and leaks (Southern California Public Radio, 2016).

Due to community and reference instrument constraints, each of the studies took place during different times of year and lasted different amounts of time. The timeline provided in Fig. 1 details deployment information.

2.3. Instrumentation — low-cost air quality monitors

In each deployment, low-cost air quality monitors dubbed Y-Pods were used for data collection. Their specifications and a list of environmental and gas-phase sensors employed in each is described in detail by Collier-Oxandale and colleagues (Collier-Oxandale et al., 2018a). Briefly, a suite of metal oxide sensors is used to assess hydrocarbons, an NDIR sensor monitors CO_2, and an electrochemical sensor measures CO. Each Y-Pod is also equipped with internal temperature and humidity sensors, and all data is stored locally. Unlike reference-grade air quality monitors, which can cost tens of thousands of dollars, each pod is made up of commercially available sensors and cost approximately $1000 to produce. Thus, for the same cost as one instrument, tens of Y-Pods can be deployed, informing us of air quality differences on more highly localized spatial and temporal scales.

Due to their small size and relatively simple power requirements, the Y-Pods can be placed in strategic locations throughout the communities of interest. Community members were actively involved in the siting process, volunteering their properties to serve as pod locations and ensuring the placements would not obstruct their day-to-day activities. Common Y-Pod siting constraints included safety, access to wall power, sufficient airflow, and likelihood of pods being unplugged or otherwise tampered with. Homes with air pollutant sources such as smoking or barbeques were avoided. Many were placed on single to multi-story roofs of homes and churches; others were placed on top of residential sheds and garages. In each of the deployments discussed, pod placements were determined collaboratively between researchers

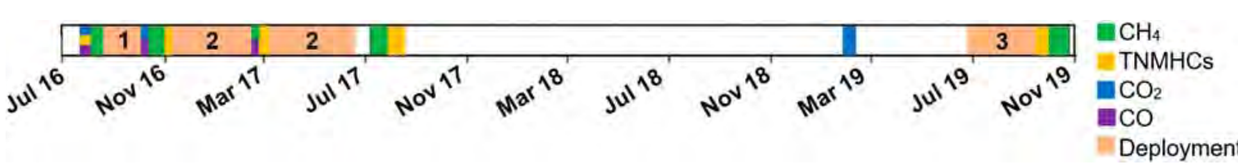

Fig. 1. Colocation and deployment timeline. The colored bars indicate which compounds were field normalized at each time, while the pink bars indicate the sensor packages being deployed in the neighborhoods.

and the involved individuals as to preserve the integrity of the study without compromising the functionality of the space.

2.4. Sensor calibration, validation, and analysis

To field normalize or calibrate, the sensors were co-located with regulatory grade air quality monitors for approximately one to two weeks at a time. Linear regression was then used to fit the sensor data to the regulatory data. One of the main advantages of this approach is that the sensors are calibrated using the same range of temperatures, humidities, pressures, and pollutant concentrations that they are exposed to throughout the field campaign (Collier-Oxandale et al., 2018a).

In previous publications involving the Figaro metal oxide sensors, a clean air normalization factor was utilized; the raw signal values from the sensors were all divided by the lowest value recorded, representing the cleanest air experienced, prior to calibration (Collier-Oxandale et al., 2018a; Collier-Oxandale et al., 2018b; Eugster and Kling, 2012). In this study, the raw sensor signals were used alone rather than normalizing. When this approach was tested, calibration and validation coefficients of determination did not improve for every pod calibration, and those that improved did so by less than 1%. We hypothesize that this clean air normalization may be more important for studies with wider temperature and humidity ranges than those observed in Los Angeles.

Due to the limited availability of reference pollutants at each colocation site, and some reference instruments being moved during longer deployments, several reference sites were used for each deployment. For deployment 3, pre and mid colocations were not available at most sites due to reference instrument failures. Descriptions of the reference instruments are presented in Supplemental Table S2.

The pods were co-located at each reference site associated with each deployment, but due to occasional power supply issues not every pod recorded sufficient data at every site. Calibration models specific to each pod were used for the following analysis.

For the first study (Deployment 1), as previously described in Collier-Oxandale et al. (2018a), the pre-deployment colocation took place on a trailer in an open field. Pods were placed 0.75–1.5 m off the ground on the side of the trailer nearest the inlet. For the post-deployment colocation in Los Angeles, pods were mounted to a railing approximately 1–2 m above the roof of the building the reference instruments were housed in, about 10 m away from and 1–2 m below the inlet. While some pollutant spikes seen by the samplers may not have been picked up by the pods due to the distances between them, the best possible configurations within the limitations of the activities at the sites were chosen. The additional colocation data collected for Deployment 1 followed the same procedure as that of the following deployments.

During the Deployment 2 and 3 colocation periods, the Y-Pods were stacked two across on top of an approximately 0.5 m high plastic container directly on the rooftop within 1–1.5 m of the reference instrument inlet. While the TNMHC site was a two-story rooftop, the rest of the samplers were on one-story roofs of trailers. The Deployment 3 study was originally intended to be a seven month long deployment, but due to reference instrument failures during the pre and mid deployment calibrations, only the second half of the deployment data was utilized. Each of these sites was operated by either South Coast Air Quality Management District or the California Air Resources Board (CARB). Maps detailing the approximate location of each reference site and monitor for each of the studies are shown in Fig. 2.

Each deployment took place during different years, and different times of year; thus, a local reference monitor was sought out as a comparison tool. Throughout 2016, the NASA Megacities project deployed Picarro G2301 and G2401 methane, CO, and CO_2 monitors on a rooftop on the USC campus (Verhulst et al., 2017), closest to the Deployment 2 site and not far from the others. No pods were placed at this precise

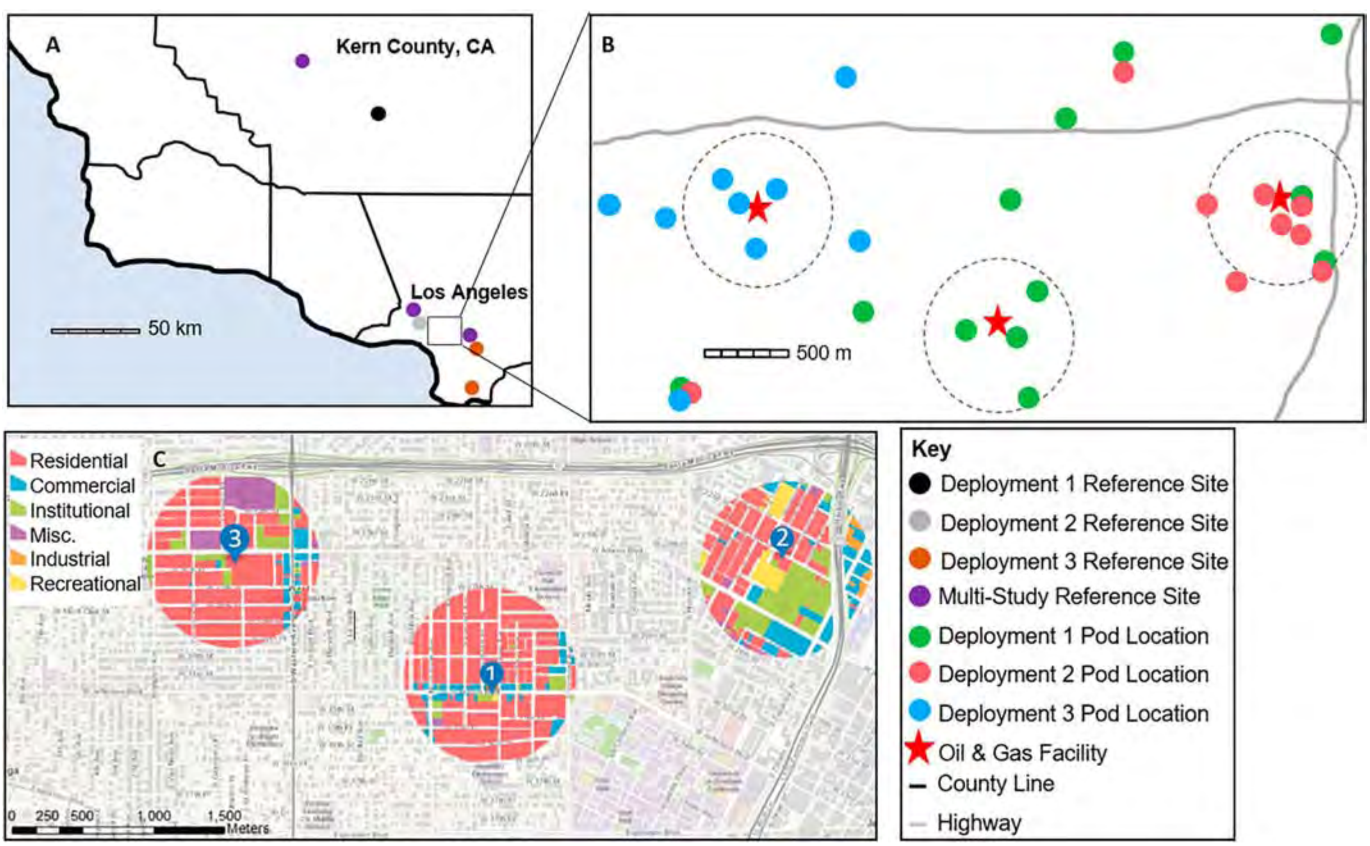

Fig. 2. A) Colocation locations, with color indicating which study/studies each reference instrument was used for; B) Sensor deployment locations for all three studies, with the oil and gas facilities and surrounding 500 m radius indicated; C) Land usage within each 500 m radius.

location. This data, discussed in Section 3.6, highlights to what extent variation among deployments was the result of yearly differences rather than the oil and gas facilities themselves.

For each deployment, a randomizing 3-fold algorithm was used to select 2/3rds of the co-location data from which to build the calibration algorithms, and the remaining 1/3rd was used as validation data. By selecting data randomly, we hoped to avoid overfitting and ensure differing environmental parameters throughout the colocations were adequately represented.

Baseline removed (subtracted) concentrations are shown to focus on spikes in the data above the normal boundary layer fluctuations which are likely caused by nearby short duration source emission plumes. This approach was originally described by Heimann et al. (2015) and later employed by Collier-Oxandale et al. (2018b) in South Los Angeles. We will briefly summarize their approach here. The deployment data was split into three-hour intervals, and the 50th percentile of the data in each interval was set as the baseline. This baseline was then smoothed and subtracted from the original field data. This includes the crests of the diurnal patterns as well as larger spikes. An example of ppm-converted data and the resulting baseline removed data from approximately three days of minute average data from the Deployment 3 study can be seen in the supplemental (Fig. S1).

2.5. Data validation

In general, as much reference data as was available for each pollutant was used for calibration and validation. However, for pollutants where multiple reference sites were used to co-locate, this approach proved challenging. Due to differing concentration ranges and multiple reference instruments being used at different sites, it was difficult for the models to fit the different sections of reference data if all the reference data was used for a single model. In general, the more similar the two reference instrument environments, the higher likelihood that the two reference data streams could be integrated into one model. This was an issue for methane throughout the Deployment 2 study, which occurred over a seven month period. A "bookending" method was used to remedy this. The pre-deployment colocation and mid-deployment colocation-data were used to model the first half of deployment only. Likewise, the mid- and post-data were used to model the second half of the deployment. For the Deployment 3 study, multiple reference instrument issues during the mid-deployment colocation made it impossible to model the full deployment without extrapolating; thus, only the second half of the deployment data was utilized.

The data collected by the pods was analyzed to ensure its validity, and periods of time that did not meet data quality checks were ultimately excluded from our analysis. After applying the models described in Section 2.4, the R^2 comparing each individual pod with the rest of the pods for each pollutant of interest was computed. Those that did not correlate well with the rest were examined more closely for power loss, sensor issues, and calibration inconsistencies for both the colocation and deployment data. The deployment thresholds for validity varied by study wave and pollutant (see Supplemental Table S3). Additionally, different thresholds were chosen for each since the calibration fits differed slightly for each deployment, and some deployments had more control sites outside of the 500 m radius. CH_4 and TNMHCs were considered the main pollutants of interest, while CO and CO_2 were used to inform the origins of CH_4 and TNMHC. All four species concentrations were used to determine which pods overall to include, although only two pods in each deployment had CO sensors, which limited our analysis.

The metal oxide sensors used to quantify methane and TNMHCs are known to deteriorate over time. The linear regression models use different coefficients for each pod for each deployment to help account for this, but by the Deployment 3, some raw signal values were noticeably experiencing "pegging", where they would record an abnormally large value periodically. Pods that experienced this throughout the duration were not used, while these spikes were removed for pods that only experienced this for a shorter period. Thus, this may have affected data quality and completeness for several of the pods throughout Deployment 3.

2.6. CO_2 sensor drift correction

In previous studies, the CO_2 sensors signals tended to drift over time to a degree that required additional drift correction measures (Collier-Oxandale et al., 2018b). The drift correction method used in this study is summarized as follows. The colocation model was first applied to the pod data. A line was then fit to the converted data, and this line was subtracted out from the fitted pod data. The atmospheric background level of CO_2 in Los Angeles, 400 ppm, was then added to this result (Verhulst et al., 2017).

The most recent year of available CO_2 reference data, 2016, was used to determine the approximate atmospheric background level for Deployment 2 and Deployment 3. For Deployment 2 specifically, since there was an approximately month-long gap between the fall and spring data due to the mid-deployment colocation, this process was repeated separately for each portion of the deployment. Since the Deployment 1 study was the shortest deployment, the CO_2 sensors did not drift significantly and were not corrected.

3. Results

3.1. Calibration model results

Based on previous studies (Collier-Oxandale et al., 2018a; Collier-Oxandale et al., 2018b), models that include temperature and humidity perform better than pollutant-specific sensors alone. Using multiple VOC sensors to model methane and TNMHCs has also been demonstrated to be more effective than single sensor models (Collier-Oxandale et al., 2019). In that previous work, the same model form produced the best fit for both methane and TNMHCs.

For Deployment 1 and Deployment 3, the elapsed time term was included to account for sensor drift. For Deployment 2, the longest deployment, this term was not included in the calibration equations for any of the pollutants. While this may seem counterintuitive, the bookending approach for that deployment ensured that for calibrations were only applied to about three months of data at a time. In addition, the Los Angeles region experienced significantly higher rainfall throughout Deployment 2 than during the other two deployments (LA Almanac, 2020). When using the elapsed time term, we hypothesize that it may have partially offset the large humidity value. Thus, the fit was worsened, and the elapsed time term was not included in the final calibration for Deployment 2.

The models for each pollutant included an intercept, temperature term, humidity term, and a term associated with the sensor for the pollutant of interest. For methane and TNMHCs, since there were two hydrocarbon sensors utilized, these both included a term for the light VOC sensor, a term for the heavy VOC sensor, and an interaction term consisting of the light VOC signal divided by the heavy VOC signal. The full models used in each deployment can be found in the supplemental (Table S4).

As shown in Fig. 3, changing the multi-sensor term from the product of the two VOC sensors, as done in previous studies, to the ratio of the two, the coefficient of determination (R^2) between pod and reference data increased while the root mean square error (RMSE) was reduced. On average, the calibration R^2 was 0.692 for Deployment 1, 0.714 for Deployment 2, and 0.799 for Deployment 3. The full results can be found in the supplemental (Table S5, S6).

The differences in R^2 and RMSE among studies can be largely explained by the reference data available. Generally, fits improved when the two book-ended colocations took place at the same reference site. It also helped if that colocation site was close to the deployment region or at least had similar concentrations of the pollutant as the deployment region. For longer colocations, having multiple colocation periods helped to account for sensor drift and seasonal changes in sensor signals.

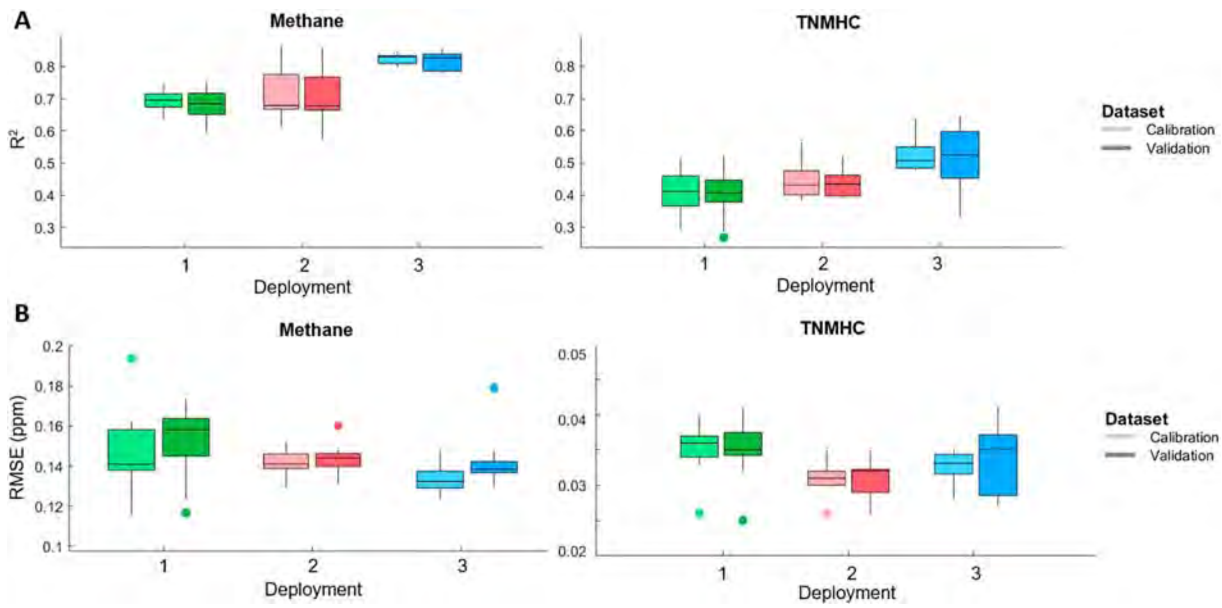

Fig. 3. Boxplots of Calibration and Validation a) R^2 and b) RMSE, grouped by study and pollutant.

3.2. Deployment 1 methane and TNMHCs

Although the data collected in the 2016 deployment has already been analyzed previously (Shamasunder et al., 2018; Collier-Oxandale et al., 2018a), in this section we will re-examine it using the improved calibration models in order to better inform the comparison across the three deployments. Deployment 1 includes the most control sites outside of the 500 m radius of the oil and gas facility; we will focus our analysis on those nearby. Fig. 4A shows the baseline removed concentrations at each location throughout this deployment.

1-E1, the only pod located due east of the facility, is not included in this analysis due to excessive power failures and limited recorded data. At the two remaining downwind pods, 1-E2 and 1-E3, methane spikes were the highest. 1-E2 saw the highest TNMHC spikes as well, although it is unclear if this is related to oil and gas activity since 1-E3 saw much more moderate spikes of the same compound. 1-W1, the monitor located closest to the facility albeit slightly west, also registered high spikes of methane but similarly failed to pick up on TNMHCs, further suggesting that methane spikes were related to oil and gas while TNMHC spikes may be another source. The high spikes of both compounds at control site 1-C4 likely has to do with natural gas distribution, discussed in further in Section 3.8.

3.3. Deployment 1 carbon monoxide

Carbon monoxide sensors were installed in two of the pods used in the study. We will focus on 1-E3, which is within the 500 m radius of the site, rather than 1-C1, located over 30 km from the neighborhood. While CO concentrations measured at this pod are correlated reasonably well with both methane ($R^2 = 0.706$) and TNMHCs ($R^2 = 0.757$), no clear patterns emerged when all three were considered together. This suggests that methane and CO are being co-emitted from the same combustion source, possibly facility related activity, some of the time, while periods of time where TNMHCs and CO are highly correlated are likely due to another combustion source, potentially motor vehicles.

3.4. Deployment 2 methane & TNMHCs

Although the facility that Deployment 2 focused on was listed as idle at the time of the study, maintenance and other activity was occurring onsite. The baseline subtracted concentrations from this deployment are shown in Fig. 4C. For this deployment, more monitors were located downwind and within the 500 m, resulting in higher concentrations on average compared to the other deployments. Most of the high methane spikes are all seen at the monitor locations closest to the oil and gas facility and at downwind sites. We have not been able to locate any other obvious sources in the area, suggesting that emissions are still related to the oil and gas facility. 2-W1, located four blocks upwind of Deployment 2, experienced the largest spikes of methane. Aside from the control site that was used in all three studies which saw elevated concentrations from a separate source, the next highest methane spikes were seen at downwind locations 2-E2 and 2-E3.

For TNMHCs, the trends are not as straightforward since there are generally more sources of TNMHCs in urban regions than methane. Some of the trends we saw for methane spikes hold true for TNMHCs, such as the larger spikes registered nearby and directly east of the site (2-W1 and 2-E4). However, other pods where we saw higher methane spikes, such as 2-E3, did not experience elevated TNMHC levels. Likewise, two of the five monitors located on the same street as the well site, recorded much larger relative spikes in TNMHCs (2-A1, 2-A2). However, the control site used in all three studies, 2-C1, showed the highest TNMHC spikes, demonstrating other local TNMHC sources in the area, as shown in Fig. 4C.

3.5. Deployment 2 carbon monoxide

CO sensors were integrated in a pod near the freeway approximately two blocks northeast of the facility (2-E4), and in a pod across the street from the facility (2-A3). Even with no active oil and gas operations in the neighborhood, CO still saw significant coefficients of determination with respect to both CH_4 and TNMHCs. Since the facility is inactive and we would not expect to see combustion markers emanating from it, the correlations are likely driven by the elevated CO emissions throughout an urban community with high traffic; this may simply prove the prevalence of these compounds across the entire region. However, since the exact scope of activities at the site during this period is unknown, we cannot rule out the possibility of them being linked to other oil and gas activities that may have been ongoing. The neighborhood surrounding Deployment 2 is also east and therefore downwind of the other two nearby active sites, so it could still be affected by oil and gas extraction activity from these upwind sites. These correlation coefficients are listed in Supplemental Table S7; both are reasonably well correlated and suggests that CO emissions may have been emitted from the same source as our pollutants of interest.

3.6. Deployment 3 methane and TNMHCs

We will similarly focus on the baseline subtracted results for the Deployment 3 site, as shown in Fig. 4E. The highest methane spikes were observed at 3-W1, the "fence-line" monitor placed approximately 9 m from the facility. Higher spikes were also observed at 3-W2, two monitors place together approximately two blocks upwind of the oil and gas facility. Proximity of each of these to the facility is thought to be responsible for the larger spikes observed at each of these. Although TNMHC concentrations were moderate for 3-W1, spikes were relatively large for 3-W2.

3-E1 and 3-E2, the two monitors east of the facility, generally saw higher methane spikes than sites further west and control sites, but they tended to be lower than those seen at monitors closest to the site. We believe the relative heights of the monitors may have affected these results. Most monitors were placed on first or second story roofs, while 3-E1 was located on the roof of a shed (approximately 2 m high) and 3-E2 was located on the roof of a seven-story building (approximately 20 m high). Since the vertical placement of these

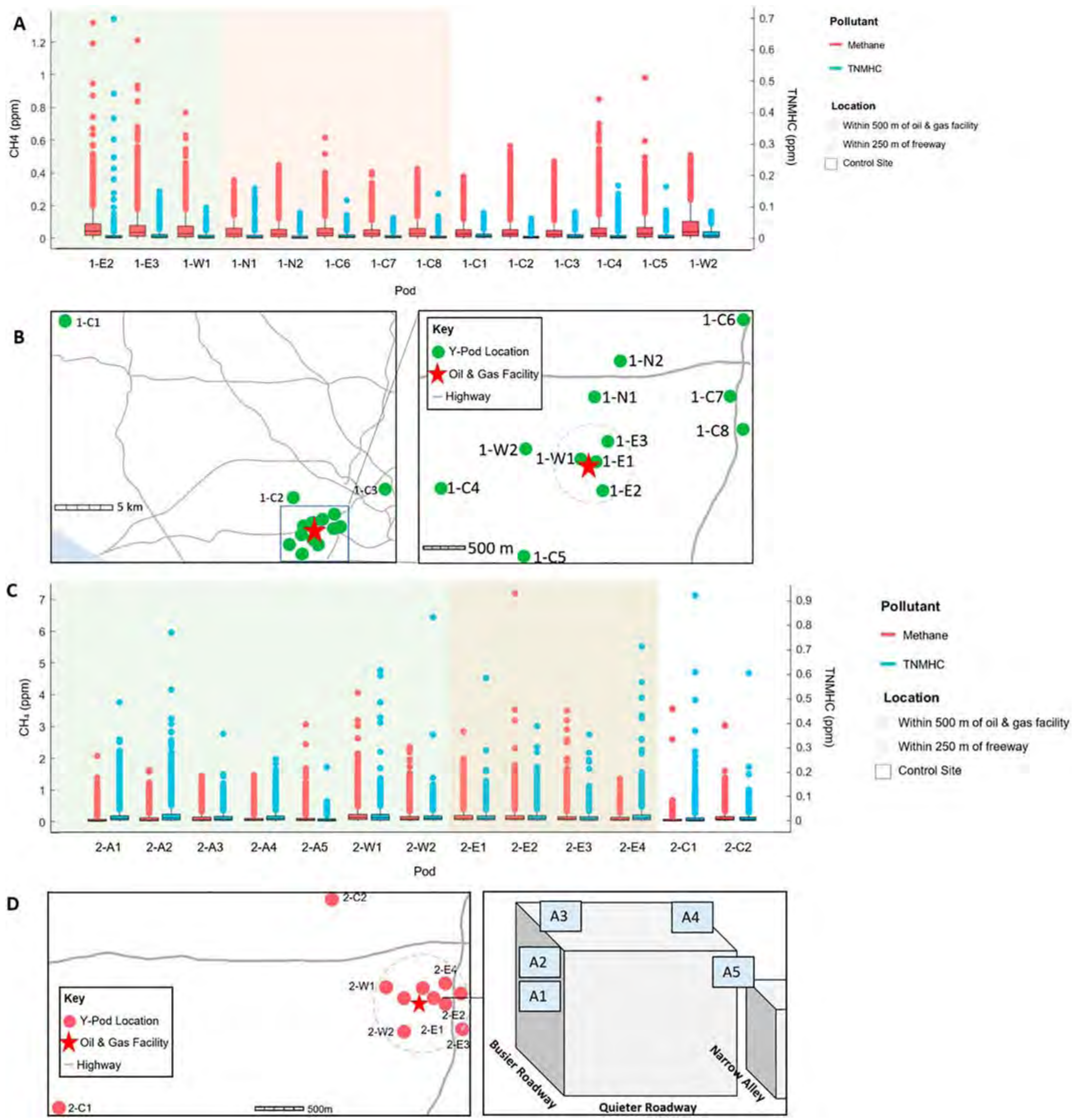

Fig. 4. 50th Percentile baseline removed boxplots for methane and TNMHCs (top); Monitor locations relative to the oil and gas facility (bottom) for: A–B) Deployment 1; C–D) Deployment 2; E–F) Deployment 3.

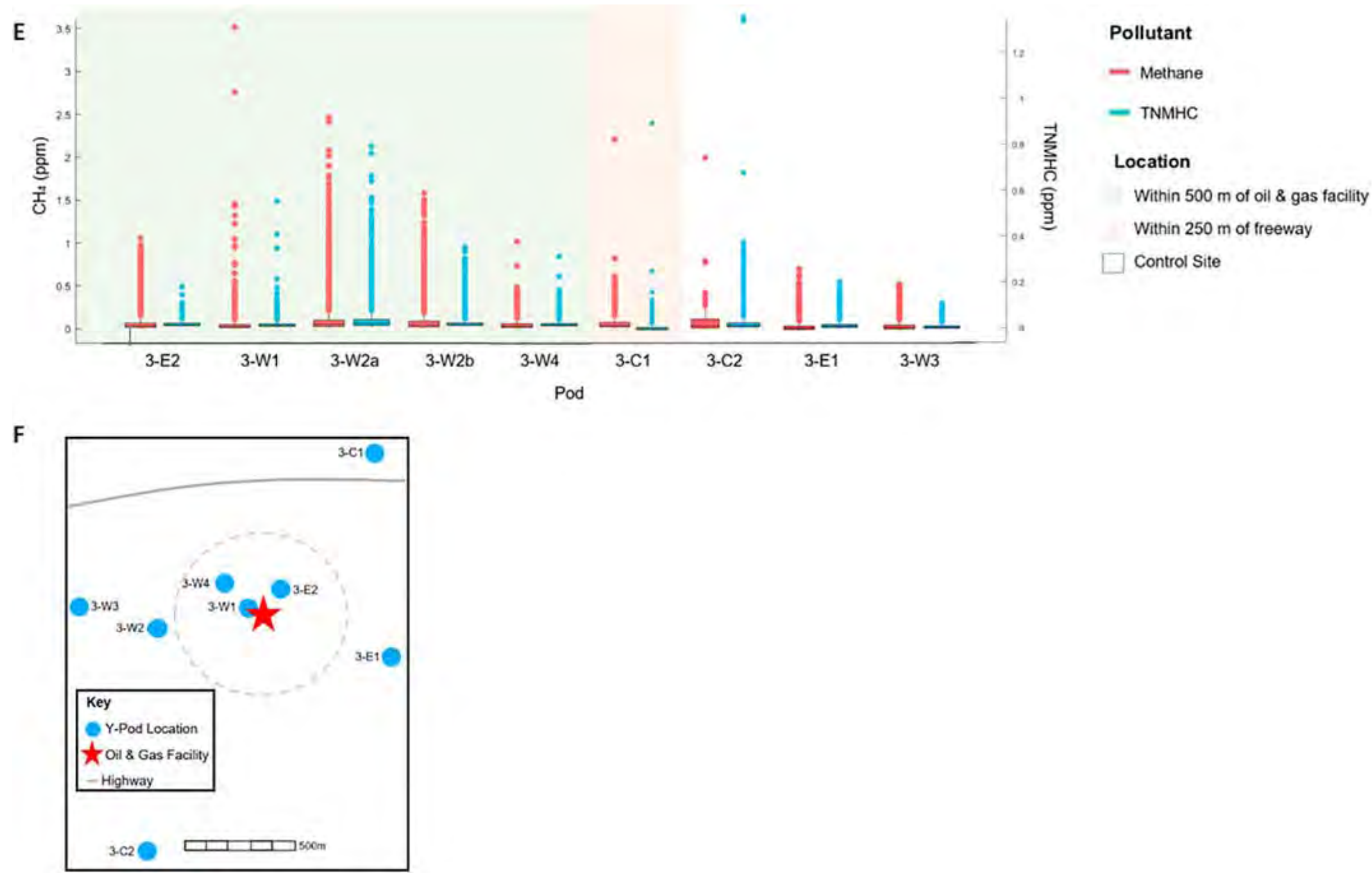

Fig. 4 (*continued*).

monitors differs greatly from the others, it is possible that each monitor was not exposed to the same plumes from the oil and gas facility, or that the downwind sites may have missed some plumes entirely based on their distance from the ground. 3-E1 appears to have recorded higher concentrations of TNMHCs than other sites, while 3-E2 captured one much higher spike.

At the control site located near the freeway, 3-C1, methane spikes remained relatively moderate, as expected. The other control site, 3-C2, experienced the largest range of spikes overall and a few large spikes. For TNMHCs, we had expected the concentrations to be elevated near the freeway, but were surprised to see the largest spikes at the control site, 3-C2.

Similar temporal patterns for methane and TNMHC spikes were observed at the 3-W2 and 3-W4 locations. Despite being slightly west of Deployment 3, each of these are very close to the site and could represent emissions from oil and gas activity. 3-E1, which was most directly downwind of the site, also shows strong correlations between the two pollutants, furthering this narrative. 3-E2, located on the highest rooftop, showed little correlation, and likely failed to adequately capture plumes from oil and gas activity. Although methane and TNMHCs were not highly correlated at 3-C2, the neighborhood control site, both were elevated for different periods of time. The natural gas pipeline nearby this site also passes through the area where 3-W2 and 3-W4 were located. The high correlations between methane and TNMHC at each of these three sites strongly suggest that the facility is an important source of spikes of both pollutants. Some observed spikes in either compound might still be attributed to the pipeline. We clearly see spikes of both methane and TNMHCs at sites nearest the oil and gas facility especially, although they do not both necessarily occur at the same time and could be emanating from different processes at the facility rather than representing the same emission event every time.

3.7. Methane and TNMHC comparison among the three deployments

For our neighborhood comparison, the pods were grouped based on whether they were placed within 500 m of the oil and gas facilities or outside of the 500 m radius. We use this 500 m radius as an indicator for impact from emissions from the oil and gas activity. Note that each site had different numbers of pods within their respective 500 m radii: 3 inside and 10 outside (800 m – 8 km away) for Deployment 1, 11 inside and 1 outside (4 km away) for Deployment 2, and 5 inside and 3 outside (800 m – 1 km) for Deployment 3. A control site used throughout all three studies was considered its own category and not included in the outside radius category for any of the sites, which we discuss in Section 3.9.

For methane, across all three deployments, we observed higher interquartile ranges and spikes within the 500 m radii than outside, indicating that all three sites are sources of methane in their respective communities. Across the three sites, Deployment 1 had the lowest concentrations overall; this is thought to be the result of the time of year and its respective atmospheric conditions, which are discussed in further detail later in this section. We see the largest range of concentrations at the Deployment 3 site, suggesting that changing concentrations could be correlated with periods of on-site oil and gas activity or maintenance activities. As mentioned in Section 3.3, the Deployment 2 oil wells ceased production in late November 2013, however maintenance activity and repairs continued at the site, so methane emissions within the 500 m radius may still related to the facility. This data is shown in Fig. 5.

To better quantify these results, we used a paired *t*-test to compare hourly averaged data from pods stationed within 500 m of the oil and gas facilities as well as within 250 m of freeways. The *p*-values of each analysis are listed in Supplemental Table S8. The *p*-values represent

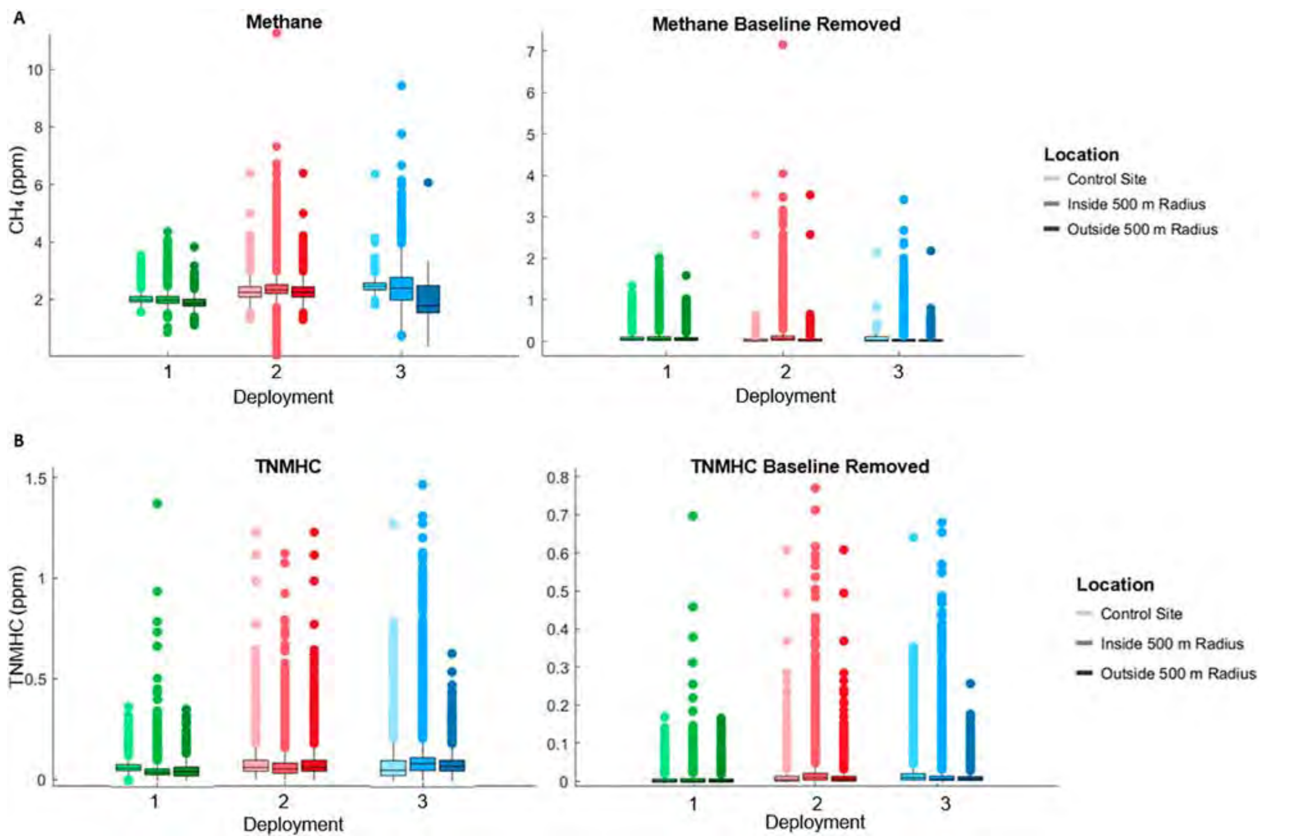

Fig. 5. Regular and baseline removed boxplots of concentrations at the control site, within 500 m of each facility, and outside the 500 m radius for: A) Methane; B) TNMHCs. The highest concentrations and spikes of methane can be seen within the 500 m radius. TNMHC spikes tended to be higher within the radius, although overall concentrations were more mixed.

whether the different locations (near a facility, away from a facility; near a freeway, away from a freeway) had significantly different medians. Although most of the individual pod data was not normally distributed, one pod from Deployment 2 (2-C1) was excluded during this analysis as it contributed to tabulation errors.

Although methane concentrations appear to be significantly different based on freeway proximity, this is more likely the result of most pods located near freeways being more than 500 m from an oil and gas facility; this mirrors the statistically significant results in the left-most column. We would not expect freeways to be a source of methane; we consider this a confounding result based on the distance between the facilities and freeways in the area.

For TNMHCs, the t-test found statistical significance for pods located near freeways for Deployments 1 and 3 only. During Deployment 2, the pods had the least distance among them overall and the most overlap between oil and gas and freeway locations, which may have contributed to the TNMHC results being flipped with respect to the other two deployments. Overall, it appears traffic is an important local source of TNMHCs, while the oil and gas facility is contributing methane.

Both Deployment 1 and Deployment 2 saw modest TNMHC concentration differences comparing the monitors within the 500 m radius compared to monitors farther away, but much higher episodic spikes signified by baseline subtracted data within the 500 m, suggesting that these events may be attributable to the sites themselves. Deployment 3 identified a larger concentration range and higher spikes within the radius as compared to pods further away. Although this could be attributed to activities at the Deployment 3 site, the oil and gas facilities seem to be a less obvious source of TNMHCs as compared to methane.

Building on our ANOVA analysis for TNMHCs, the pods are plotted based whether they were within 250 m of a freeway or highway in Fig. 6. From our initial analysis, higher TNMHC concentrations were not observed near major roadways, which is not in line with what we would expect. Although it is worth noting that across all three deployments, only one of the pods located near a freeway was downwind of the prevailing wind direction, so emissions may not have been picked up on as expected.

The location of pods in each community relative to their respective oil and gas facilities may also have influenced these results. In the Los Angeles region, the prevailing wind direction is westerly, blowing inland from the coast (Weather Underground - Los Angeles, CA Weather). However, our ability to examine downwind effects was limited by the monitor placement and data completeness. For Deployment 1, there was only one pod located due east of the facility, and this pod suffered from intermittent power loss and only recorded about two weeks' worth of data throughout the two month deployment. The pod southeast of the Deployment 3 site was just outside of the 500 m radius. This pod and the northeast pod alike may have additionally been affected by height differences, further discussed in Section 3.6. Deployment 2 had the most optimal downwind pod placements, with two sites nearly directly downwind of the site, although we would not expect to see spikes from the facility if it was truly idle. Across all three sites, neither CH_4 nor TNMHCs displayed clear trends with respect to temperature, wind direction, month, or time of day.

We also investigated the hourly trends for each of the main compounds to determine how pollutants concentrations in the boundary layer may have changed throughout the day. We used Pacific Standard Time; our values are consistent with meteorology but may vary with human activities such as traffic and hours of oil and gas operation that vary with daylight savings. These diurnal concentration trends are shown in Fig. 7. Again, we separate pods based on proximity (control, within 500 m and outside 500 m). We also included data on most of the key pollutants collected at USC, closest to the Deployment 2 neighborhood, by NASA's Megacities Project throughout 2016. The rightmost graphs show this dataset sorted according to time of year; we show

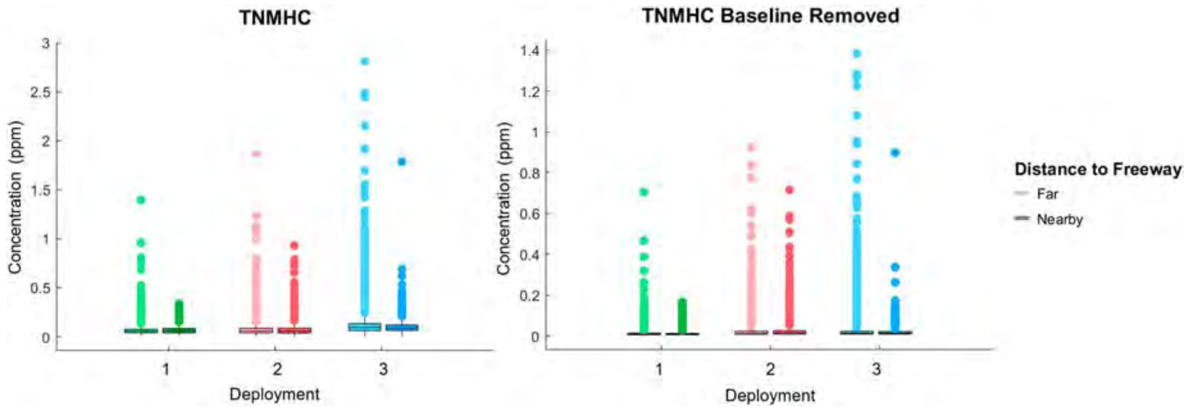

Fig. 6. A) Regular and B) baseline removed boxplots of TNMHC concentrations within 250 m of a freeway and elsewhere throughout each community.

three Megacities diurnal profiles, each corresponding to the same time of year as one of the three deployments as we are trying to remove seasonal effects from the neighborhood comparisons. The shaded regions on each chart indicate the 95% confidence intervals.

Changes in the height of the planetary boundary layer are primarily driven by convection from the Earth's surface; as temperatures rise throughout the day, the boundary layer rises (Schindler, 2013). The slightly different elevations of each community are not thought to

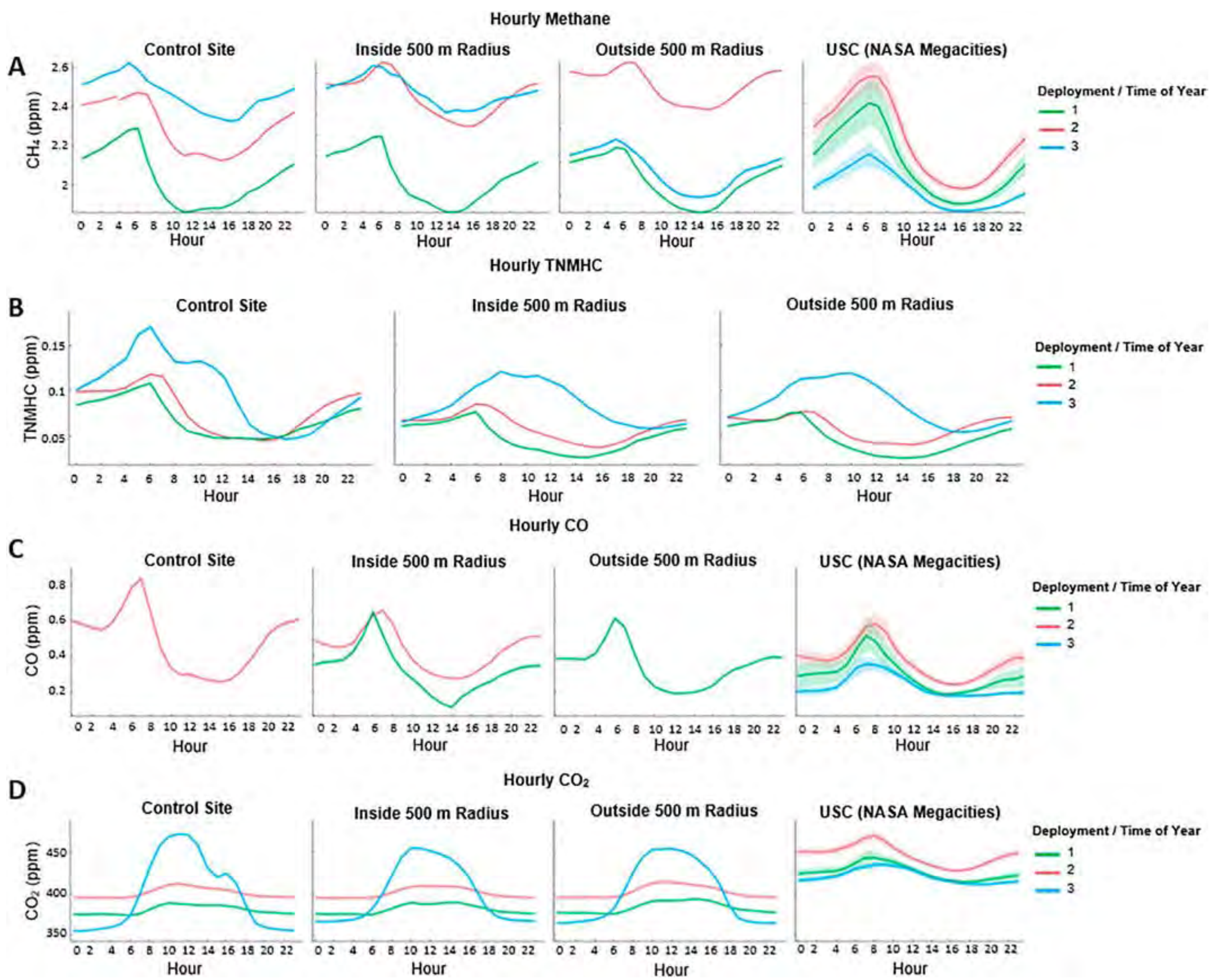

Fig. 7. Concentrations grouped by hour of day for (L to R): a control site; pods within the 500 m radius of each facility; pods outside the 500 m radius of each facility; reference data collected by the NASA Megacities project. Each row is a different pollutant: A) Methane; B) TNMHCs; C) CO; D) CO_2.

have significantly impacted these results, as the largest difference in elevation among the three communities was only approximately 50 m (Los Angeles County Public Works, 2020); we expected to see compound concentrations rising and falling at similar times of day for each of the three sites. The inclusion of reference and control site data better informs to what extent seasonality and long-term changes affected our comparison.

Based on the reference data collected by NASA, each of the compounds trended higher during the winter and spring, when the Deployment 2 study took place. This might explain why most concentrations near Deployment 2, the idle site, are higher than near Deployment 1, the first active site. Concentrations appear to be slightly higher during the fall (Deployment 1) than over the summer (Deployment 3), although seasonality did not appear to affect hourly trends or boundary layer differences, only the range of concentrations overall. Since most Y-Pods were placed on one or two story roofs, while the reference instrument inlet was mounted approximately 2 m above the roof of an 11 story commercial building, hourly trends were expected to be slightly staggered due to this significant difference in height. One monitor placed on a seven-story roof throughout the deployment saw trends similar to the Megacities reference data at a similar elevation and building placement as opposed to the rest of the sites, which were closer to ground level. The reference instrument represents the larger seasonal trends over the course of a year, while our monitors show shorter term spatial and temporal differences much closer to human activities.

We also compared the concentrations of TNMHCs against methane in Fig. 8; correlation might indicate a shared source. Although there are countless TNMHC sources in the Los Angeles area, narrowing emission events down to when they correlate with methane, which is predominantly associated with oil and gas activities, could identify TNMHCs associated with oil and gas activity. This data was similarly grouped by proximity, control site near the pipeline as well as pods inside and outside the 500 m radius of each site. At Deployment 2, the spreads and linear fits are the most similar to each other while showing the weakest correlations overall. The baseline removed comparisons similarly lack patterns, suggesting that the methane linked to the facility was not accompanied by plumes of other hydrocarbons. At Deployment 1, the trends were the most linear, but once again did not vary significantly based on proximity to oil and gas activity for the full data or baseline removed spikes. The lower overall concentrations throughout this study could explain part of the uniformity. For Deployment 3, while the inside-outside pods have parallel trendlines, we can see several “fingers” diverging from the main plume for the data within the 500 m radius of the oil and gas facility only. This suggests that at certain times, TNMHCs and methane are extremely well correlated and likely associated with oil and gas emissions. The baseline removed data furthers this narrative; episodic spikes nearby the site clearly show a much higher correlation than those farther away, once again suggesting that the Deployment 3 site is a more significant source of both compounds than the other sites.

As we previously saw, the concentrations of both compounds at the control site varied by study and time of year. Thus, there is not too much uniformity across these plots, although all three show correlations similar or slightly better than those experienced at the other neighborhood locations. The baseline removed plots do not inform much, suggesting that spike events emanating from the pipeline at the control site for both compounds occurred, but not necessarily at the same time.

3.8. CO and CO_2 comparison among the three deployments

While CO and CO_2 were not extensively studied on their own, since they are the products of combustion activities, they were used as a comparison tool against CH_4 and TMHCs to determine what emissions might be associated with combustion events, whether from oil and gas activities or other anthropogenic sources such as auto emissions. Note that CO data was not available from the NASA source for November and December 2016 in Fig. 7.

The lack of CO data at the upwind comparison site and throughout the Deployment 3 makes it difficult to draw conclusions about combustion-related emissions in the neighborhood. CO emissions peaked about two hours later at the USC reference site as opposed to our pods; this is likely due to the large differences in height between NASA's monitors and ours. Peaking around 7 am at ground level is consistent with traffic patterns in the early morning. Deployment 2 remains slightly higher than Deployment 1 within the 500 m radius; this same trend was seen at the reference site, signaling that this is likely explained by the time of year, not oil-related activity at the active facility.

For CO_2, Deployment 3 saw drastically elevated concentrations all throughout the neighborhood, which may be attributed to plant respiration at ground level during the summer months. It does not appear to be related to episodic flaring or other oil and gas activities due to its widespread recurrence. The neighborhoods studied are considered low-density residential (Liberty Hill Foundation, 2015); many homes in the area have lawns and some have trees, although the area is still urban (Longcore et al., 2004). While Deployment 1 and Deployment 2 were in agreement both with each other and the seasonal trends shown in the reference data, despite some hourly shifting from the different elevations, these trends are not thought to be necessarily linked to complete combustion or the oil and gas facilities themselves.

3.9. Methane and TNMHCs at the control site during all three deployments

To help assess the seasonal and year-to-year impact on concentration differences, one pod was placed at the same site upwind of the three facilities during each deployment; each time this control site was outside of the 500 m radius and upwind from the oil field. However, we frequently observed relatively elevated concentrations at this control site, as per Fig. 7. Upon subsequent investigation, we identified a natural gas distribution pipeline runs along the street where these control pods were sited (SoCal Gas, 2020). Fugitive emissions from the pipeline might explain relatively elevated methane and TNMHC levels at this site and represent another source in the area rather than a true “control” concentration.

In Fig. 7, the concentration ranges and hourly trends seen at the control site for each study mirror those seen at the pods nearest oil and gas activities; yearly trends seem to dominate the results we see at each site. The exception to this is the concentrations of methane throughout the Deployment 3 study; concentrations hovered approximately 0.4 ppm higher within the 500 m radius of the facility and at the control site located along the pipeline as opposed to sites in other parts of the community. This signals that the Deployment 3 facility and other oil and gas operations in the area are the main contributors of methane in the neighborhood. The time of year of the Deployment 3 study also saw the lowest concentrations at the USC reference site, furthering the narrative that this elevated methane is from the oil and gas activity in the neighborhood and not influenced by the time of year or other variables in the area. Overall, we expected to see the concentrations of non-reactive compounds such as CH_4 rise and fall with the boundary layer itself; each peak roughly around 7 am for both our monitors and the reference site accordingly.

The control site was used as the main point of reference for TNMHCs as a reference instrument was not available in the Los Angeles area. Although concentrations for both Deployment 1 and Deployment 2 bottomed out around 2 pm each day, TNMHCs all throughout the Deployment 3 neighborhood were elevated and did not level out until between 6 and 8 pm. Two years passed between the first two deployments and the third; shifts in the area over that period could inform why Deployment 3 sees different trends differs from the previous two. The uniformity of emissions across all three locations for all three sites again suggests that the oil and gas operations were not as major a source of TNMHCs as for other compounds, such as methane.

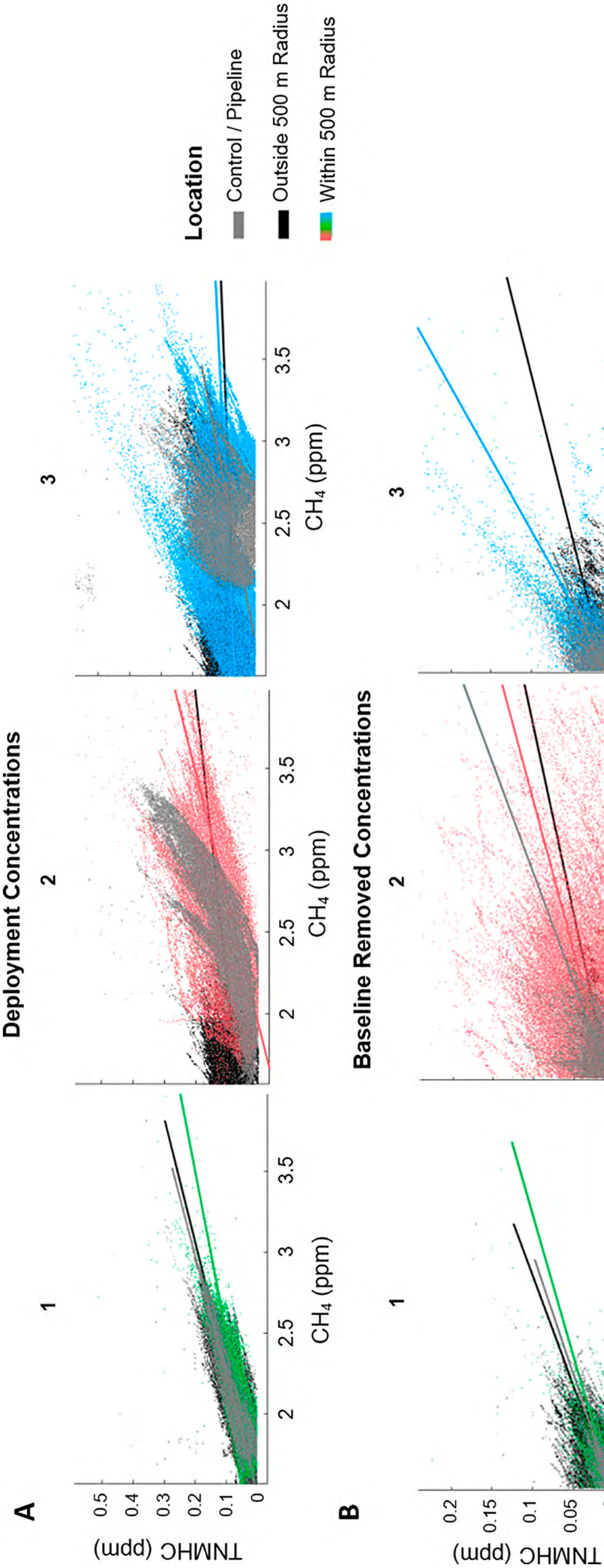

Fig. 8. Trends between Methane and TNMHCs colored by location: at the control site, inside the 500 m radius, and outside the radius. The rows are split by: A) deployment data; B) baseline removed data.

4. Discussion

4.1. Key findings

This study is one of the first studies on air quality impacts of urban oil drilling, and one of the most comprehensive as it spans four years and three neighborhoods. Chiefly, air quality is a major concern near oil and gas facilities, especially those that have homes, schools, and other sensitive land use within the immediate area. Both methane and TNMHCs are linked to oil and gas activities, with methane being the more significant of the two; the myriad sources of TNMHCs in a complex urban environment are more difficult to disentangle, while methane emissions can be attributed to oil and gas facilities and distribution pipelines with a higher degree of certainty.

Although the daily production and precise activities at each site are murky due to self-reporting and temporal aggregation, we attribute many of the differences among the three sites to be the result of the presence of oil and gas facilities, although some of the larger trends were likely influenced by the year and time of year. Deployment 3 saw the largest spikes of methane and TNMHCs in the immediate vicinity of the facility, while Deployment 2 also recorded large spikes despite being an idle facility. Deployment 1 had the lowest concentrations overall, but this is consistent with the year and time of year trends observed at other reference sites; the spikes surrounding this facility, albeit smaller than those throughout the other two deployments, are consistent with what we consider to be emissions from an active oil and gas facility.

4.2. Environmental justice implications

Numerous studies have shown that ambient air pollution is generally worse in low-income and people of color neighborhoods than in their higher income or whiter counterparts (Kim et al., 2019; Dadvand et al., 2015; Lin et al., 2013; Sun et al., 2017). Deploying decentralized neighborhood air quality sensors can facilitate understanding of difference in air quality in diverse and often understudied neighborhoods. Low-income residents are further less likely to be able to mitigate their exposure, as they are less likely to have air conditioning and more likely to leave windows open, increasing their daily exposure to outdoor pollutants (Sun et al., 2017). Several other studies have highlighted how income bracket may dictate a community's air quality (Lin and Zhu, 2018; Yu and Stuart, 2016; Liu et al., 2016).

Studies have similarly demonstrated that the impacts of drilling, refining, flaring, spills or leaks, and pipelines disproportionately affect people of color and low-income populations across the US (Kroepsch et al., 2019; Johnston et al., 2020). In Los Angeles, California, of the 75 communities the Pacific Pipeline intersects, 74 had higher percentages of people of color, and all 75 had higher percentages of non-English speakers compared to the national average at the time of its construction. In addition, 62 of these neighborhoods had per capita incomes below the national, state, county, and city averages (O'Rourke and Connolly, 2003; Impact Assess. Inc., 1995). As presented in Section 2.2, the specific Los Angeles communities studied in this work are no exception to these trends, with community oil and gas operations affecting communities that are both low income and historically disenfranchised. The inherent inequity of oil and gas infrastructure in Los Angeles is one facet of the environmental justice issues plaguing the city's Black and Latino members; this study aimed to shed light on the exact pollutant concentrations these Angelenos faced over long periods of time. This exposure data has also been made available to participants in the study, and will be compared with newly-collected health and demographic information in a future work.

4.3. TNMHCs in urban communities

In this work, we used TNMHCs as a proxy for VOC sources of potential health concern, generalized into a singular category rather than speciated into individual hydrocarbons. As mentioned in Section 1.1, the health risk of TNMHCs depends on the exact compounds emitted, which we were unable to assess in this study. Here, we will reference other TNMHC studies to help put our results in context.

In a six-year study of 28 U.S. cities, the most significant TNMHC source was vehicular emissions, followed by oil and gas activities in cities such as Los Angeles and Baton Rouge (Baker et al., 2007). Another study found that TNMHC concentrations in Cincinnati, Ohio ranged from 0.4 to 3 ppm, while concentrations in Los Angeles hovered between 0.5 and 6 ppm (Altshuller et al., 1966). Concentrations in both cities peaked around heavy traffic times, although the significantly larger range in Los Angeles might be attributed to the different climates, populations, and the prevalence of oil and gas in the latter. Despite this study having taken place in the 1960's, the three oil and gas facilities analyzed in this study had begun operations around then (California Department of Conservation, 2012). While TNMHC concentrations are bound to be high in most urban areas with heavy traffic, Los Angeles seem to have higher concentrations relative to other cities.

In Los Angeles, SCAQMD studies have found higher concentrations of VOCs at reference sites located nearby or downwind of freeways as opposed to other locations situated further from heavy traffic (South Coast Air Quality Management District, 2012a). At the reference site utilized in Kern County, CA, typical TNMHC minutely averages ranged from 0 to 1.15 ppm throughout 2019, lower than those noted in our Los Angeles communities. Note that while oil and gas activities are present in this area, the region is considered rural and the site is located approximately 15 km from the nearest freeway. This makes it more difficult to determine if all pods in LA were influenced by traffic activity, or if sensor placement at those nearest freeways was insufficient to pick up on larger trends.

Whether or not these levels are likely to adversely impact human health depends greatly on the exact species of hydrocarbons emitted. While some guidelines are in place in California for non-speciated TNMHCs from specific sources, there are no true limits or guidelines on what concentrations are safe for humans as the level of danger varies significantly based on the specific hydrocarbon (South Coast Air Quality Management District, 2012b).

For hydrocarbons that have been linked to cancer, such as benzene, multiple studies by Glass et al. (2001, 2003, 2005) suggest that cumulative exposure increases the risk of leukemia at an approximately 2 ppm threshold over the course of a year. However, the same group was unable to pinpoint a threshold for benzene exposure at which there was no risk of adverse health outcomes (Glass et al., 2001; Glass et al., 2005). Even at levels below 1 ppm, which is aligned with the episodic spikes in our studies, the risk of other adverse health effects is palpable (Glass et al., 2003; Smith, 2010). Short-lived spikes may not represent the most worrisome exposure outcomes, but can affect the health of community members nonetheless.

4.4. Limitations & lessons learned

For the physical setup of our experiment, since we worked within the constraints of those who were willing to house our monitors, some placements were not ideal. Future recommendations for placement include a mix of upwind and downwind monitors for each deployment and focused on having monitors directly downwind of each oil and gas facility. The studies were also limited by occasional power and data consistency issues. For instance, the one monitor directly downwind of the oil and gas facility during Deployment 1 frequently lost power, rendering the sparse data unusable for our analysis. The loss of data at a key monitoring site hindered our ability to adequately address spatial differences associated with wind direction. Additionally, the monitor location selected as a control site across all three deployments ended up being placed atop a natural gas pipeline, confounding our results as this was an additional, unintended methane source in the area.

Since each of the deployments took place during different years, during different seasons, for different lengths of time, seasonal trends may have affected the comparison among all three sites. Additionally, the production data that the facilities self-report is published monthly, so we cannot examine daily trends with respect to the monitor observations. Based on the results of these studies and the continuing complaints by residents in each area, we have reasons to be skeptical of the self-reported data that has been made available, making it increasingly difficult to draw firm conclusions. These factors confound our ability to assess the cause of elevated concentrations, whether it be seasonal atmospheric conditions, oil and gas activity, another factor, or a combination of these three.

While this is one of the most comprehensive studies to date on urban oil and gas activities in the area, future studies are needed to improve our understanding of impacts as well as mitigation strategies. For instance, conducting each of these studies at the same time of year or even simultaneously would have assured more comparable data. Additionally, since spikes were generally seen downwind of oil and gas facilities, we would recommend placing as many monitors east of the sites as possible to fully understand the aggravated health effects those living or working in those areas may experience in addition to those within the 500 m critical radius. Likewise, the placement of monitors relative to freeways could be improved upon to better understand the influence of traffic on TNMHCs. Access to speciated hydrocarbon data could also be beneficial; colocation with a reference instrument that measures harmful TNMHCs such as benzene could better inform the community of their risk level. Overall, we find that the neighborhood-scale monitoring campaigns provide insights into local sources, episodic emissions events and refined spatial air quality data. This is especially useful in complex urban areas such as Los Angeles, where population density, sources, and the terrain can make air quality events even more localized on small spatial and temporal scales.

4.5. Broader implications

Although oil and gas activities are not present in most major cities, additional locations face the same unique challenge of having multiple major pollutant sources in a complex urban environment. Other major cities with significant oil and gas activity include Abu Dhabi in the United Arab Emirates, Rio de Janeiro in Brazil, Calgary in Canada, and Houston in the United States (Cunningham, 2015). Over 17 million people in the United States alone live within a mile of an active oil or gas facility (Bienkowski, 2017). Despite the staggering amount of people affected by oil and gas in cities and other areas alike, research on exposure and health effects in proximity to oil and gas remains limited. Few sensor network studies have been utilized in the cities mentioned, and even less attention has been paid to hydrocarbons and oil and gas emissions specifically. Since this study was successful in determining hydrocarbon emissions in a set radius of oil and gas activities, it could be reproducible in other cities, so long as reference-grade instruments are accessible in each location of interest for calibration. Through our field normalization approach, pods need to be co-located in an environment similar to that of the deployment, as the calibration models are not meant to extrapolate. Thus, the availability of reference-grade instruments may be a barrier to replicating this study in other areas of interest, while the use of our sensor network could easily be implemented in another city for source attribution purposes.

5. Conclusions

This is the only multi-year study centering on oil and gas activity in urban Los Angeles, and one of the only focusing on the impacts on homes and schools in the immediate area. It also compares multiple facilities drawing from the same oilfield, taking the production data at each site into account. Over the three years of monitoring deployments, the differences in the concentration ranges among the three are thought to be mostly attributed to differences in yearly and monthly trends rather than the oil and gas facilities themselves. We continued to observe elevated local emissions near the idle well site indicating the potential role that fugitive emissions or maintenance activities can have on local air quality. The presence of oil and gas facilities lead to elevated air pollutant concentrations, specifically methane, in the surrounding neighborhoods.

CRediT authorship contribution statement

Kristen Okorn: Software, Formal analysis, Data curation, Writing – original draft. **Amanda Jimenez:** Investigation. **Ashley Collier-Oxandale:** Investigation, Writing – review & editing. **Jill Johnston:** Conceptualization, Writing – review & editing. **Michael Hannigan:** Conceptualization, Writing – review & editing.

Data availability

All raw and converted Y-Pod data as well as the accompanying MatLab code for data processing are available upon request; please contact the main author. Reference data provided by South Coast Air Quality Management Division and the California Air Resources Board is available upon request by emailing PublicRecordsRequests@aqmd.gov and prareqst@arb.ca.gov, respectively. Reference data courtesy of NASA (Megacities Project) is available at: https://megacities.jpl.nasa.gov/public/Los_Angeles/In_Situ/USC/2016_Measurements/.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.146194.

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Exhibit 10 of 13 - PSE 2019. Literature Review

Human health and oil and gas development: A review of the peer-reviewed literature and assessment of applicability to the City of Los Angeles

Seth B.C. Shonkoff, PhD, MPH[1,2,3], Lee Ann L. Hill, MPH[1]

[1] *PSE Healthy Energy, Oakland, CA*
[2] *Department of Environmental Science, Policy, Management, University of California – Berkeley, Berkeley, CA*
[3] *Lawrence Berkeley National Laboratory, Berkeley, CA*

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Table of Contents

List of Abbreviations

ALL	acute lymphocytic leukemia
CARB	California Air Resources Board
CCST	California Council on Science and Technology
CI	confidence interval
COGCC	Colorado Oil and Gas Conservation Commission
CRS	chronic rhinosinusitis
DOGGR	Division of Oil, Gas and Geothermal Resources
EOR	enhanced oil recovery
FCR	finding, conclusion, and recommendation
H_2S	hydrogen sulfide
HAP	hazardous air pollutant
HI	hazard index
LACDPH	Los Angeles County Department of Public Health
LBW	low birth weight
LOD	limit of detection
mmHg	milligrams of mercury
NHL	non-Hodgkin lymphoma
NMHC	non-methane hydrocarbon
NMVOCs	non-methane volatile organic compounds
OR	odds ratio
PAH	polycyclic aromatic hydrocarbon
SB 4	Senate Bill 4
SCAQMD	South Coast Air Quality Management District
SGA	small for gestational age
SNAPS	Study of Neighborhood Air near Petroleum Sources

SOx	sulfur oxides
TAC	toxic air contaminants
ROGER	PSE Healthy Energy Repository for Oil and Gas Energy Research
UNGD	unconventional natural gas development
US EPA	United States Environmental Protection Agency
VOC	volatile organic compound

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About PSE Healthy Energy

Physicians, Scientists, and Engineers for Healthy Energy (PSE) is a multidisciplinary, non-profit research institute that studies the way energy production and use impact public health and the environment. We share our work and translate complex science for all audiences. Our headquarters is located in Oakland, California.

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1.0. Executive Summary

An April 2017 motion from City of Los Angeles council member Wesson directed the Petroleum Administrator to work with the Los Angeles County Department of Public Health and other agencies to assess the health effects of oil and gas production in the City of Los Angeles. Physicians, Scientists and Engineers for Healthy Energy (PSE) was retained by the Office of Petroleum and Natural Gas Administration and Safety in the City of Los Angeles to conduct a review of the peer-reviewed literature focused on public health and oil and gas development and assess the applicability of this body of literature to the context of the City of Los Angeles. This study incorporates the findings contained in the public health sections of the California Council on Science and Technology Senate Bill 4 Independent Scientific Study (CCST, 2015) and incorporates a review of the peer-reviewed literature published since 2015.

For studies published since 2015, in this assessment we focus primarily on two broad categories of studies: (1) studies of human health hazards, risks and impacts in the context of air pollution from upstream oil and gas development, and (2) human health hazards, risks and impacts as a function of distance from and density of upstream oil and gas development. A single peer-reviewed oil and gas development and health study focused in California has been published to date. There are however a variety of results and conclusions drawn from the greater peer-reviewed literature outside of California that are applicable in many ways to the City of Los Angeles context. From the findings of this assessment, we compiled the following findings, conclusions and research and policy recommendations (FCR):

FCR-1: Conduct studies in the State of California to assess the relationship between oil and gas development and public health as a function of distance.

Finding: Only one peer-reviewed oil and gas development and health study has been conducted in the State of California. There are however a variety of results and conclusions drawn from the greater peer-reviewed literature outside of California that are applicable to the California context.

Conclusion: There is a dearth of peer-reviewed studies on oil and gas development that are specific to the State of California and the City of Los Angeles, yet there are results and conclusions drawn from the weight of the peer-reviewed literature outside of California that are relevant to the California context.

Recommendations:

(1) Conduct health studies in the City of Los Angeles on the health dimensions of oil and gas development as a function of distance and oil and gas well density that incorporate multiple potential environmental and exposure pathways. These studies should assess active oil and gas development and could also include inactive oil and gas development such as plugged and abandoned wells and associated infrastructure. Given the increasingly expansive body of

health literature on the topic, consider promulgating health-protective policies based on the existing literature.

(2) Ensure that field-based air pollution monitoring at the community scale and in close proximity to oil and gas development continues and expands and that it is implemented in ways that properly characterize emissions from these processes. This includes but is not limited to ensuring that air monitoring methods are deployed to capture the intermittent and periodic nature of emission events throughout the oil and gas development process and that there is access to well pad-level activity information to inform the monitoring approaches.

FCR-2: Consider the implementation of a minimum surface setback requirement, caps on oil and gas development density and deployment of increased emission control strategies in the City of Los Angeles.

Finding: The majority of peer-reviewed studies that assess human health in the context of oil and gas development as a function of distance and density have noted increased hazards, risks and health impacts as distance decreases and density increases. The density of oil and gas development in oil and gas-producing neighborhoods in and near the City of Los Angeles is as high or higher than densities of oil and gas development associated with health impacts in out of state studies.

Conclusion: The development of oil and gas close to human populations poses higher risks of exposure to health-damaging air pollutants than the development of oil and gas further away from human populations. The same trend tends to exist for higher vs. lower density of oil and gas development.

Recommendations:

(1) Agencies with jurisdiction should consider the implementation of minimum surface setbacks between oil and gas development and sensitive receptors including but not limited to residences, schools, daycare centers and hospitals in the City of Los Angeles. The decision as to how large the setback is should also take the available body of epidemiological studies on oil and gas development into account. Studies to date conducted in regions with migrated hydrocarbon reservoirs have found associations with increased health risks associated with oil and gas development ranging from approximately 0.1 miles (500 feet) to one mile (5,290 feet). As such, a setback greater than 500 feet and up to 5,290 feet should be considered.

(2) Given that the *density* of oil and gas development has been found across a number of health studies to be associated with increased health risks, agencies with jurisdiction may consider limiting the density of wells and other oil and gas development infrastructure at oil and gas producing areas within and near the City of Los Angeles.

(3) Best available emission control technologies and management approaches should be deployed on all oil and gas wells and ancillary infrastructure to limit emissions of health-damaging air pollutants. Target air pollutants should include both those that are regularly monitored for (e.g., Criteria Air Pollutants, Toxic Air Contaminants and aromatic hydrocarbons such as benzene)

as well as those pollutants that are less frequently monitored for including, but not limited to chemicals reported to SCAQMD pursuant to Rule 1148.2 that are known air pollutants.

2.0. Introduction

The City of Los Angeles is a global megacity where intensive oil development occurs in close proximity to large urban populations. This co-occurrence of dense oil and gas activities and human populations poses potential human health hazards, risks and impacts that may be less present in areas of lower population density. Pursuant to California Senate Bill 4 (Pavley, 2013) (SB 4), the California Council on Science and Technology (CCST) conducted an independent scientific assessment of well stimulation in California with chapters focused on potential hazards and risks of well stimulation (e.g. hydraulic fracturing) and oil and gas development in general (CCST, 2015). Within this report were two health assessments: one focused on human health and oil and gas development across the state (Shonkoff et al., 2015a) and a human health case study specific to the Los Angeles Basin (Shonkoff et al., 2015b). These human health assessments provided a review of the peer-reviewed literature on oil and gas development and human health hazards, risks and impacts published between 2009 to 2014. Since the CCST SB 4 Report (2015), numerous additional studies focusing on oil and gas development and human health have been published. In this report we review the public health findings presented in the CCST SB 4 Report (Shonkoff et al., 2015a; Shonkoff et al., 2015b) and then summarize the findings of the peer-reviewed literature on oil, gas and health published since then (2015 - 2018), with a particular focus on health outcome studies and studies that have an air pollution focus. We then evaluate this body of literature in the context of oil and gas development in the Los Angeles Basin and where possible in the City of Los Angeles in particular.

2.1. Our approach to hazard and risk

The terms *hazard* and *risk*, while often used interchangeably, have different implications in the field of risk assessment. A *hazard* is defined as any biological, chemical, mechanical, environmental, or physical stressor that is reasonably likely to cause harm or damage to humans, other organisms, the environment, and/or engineered systems in the absence of control (Sperber, 2001). *Risk* is the probability that a given hazard plays out in a scenario that causes a particular harm, loss, or damage (National Research Council, 2009). Determining risk, or the probability of harm, requires a receptor (e.g., human population) to be exposed to the hazard, and often depends on the vulnerability of the population (e.g., age, pre-existing conditions) (Shonkoff et al., 2015a). Living in close proximity to oil and gas development may increase the likelihood of populations to come into contact with various hazards, including air pollutants.

2.2. Impetus for this report

An April 2017 motion from City of Los Angeles council member Wesson directed the Petroleum Administrator to work with the Los Angeles County Department of Public Health and other agencies to assess the health effects of oil and gas production in the City of Los Angeles. Physicians, Scientists and Engineers for Healthy Energy (PSE) was retained by the Office of Petroleum and Natural Gas Administration and Safety in the City of Los Angeles to conduct a review of the peer-reviewed literature focused on public health and oil and gas development and assess the applicability of this body of literature to the context of the City of Los Angeles.

2.3. Focus of this review: local air pollution and health dimensions of oil and gas development

In this report we review the findings from the CCST SB 4 Report (2015) and synthesize the available peer-reviewed literature on oil and gas development, air quality and human health that has been published since. We finalize our assessment with a discussion of the applicability of this body of peer-reviewed literature to the context of oil and gas development and human health in the City of Los Angeles and provide conclusions and recommendations.

3.0. Approach

In alignment with the approach of the health assessments in the CCST SB 4 Report (Shonkoff et al., 2015a and Shonkoff et al., 2015b), in this report we employ a top-down assessment to evaluate hazards associated with *upstream* oil and gas development by starting with population health outcomes and working backwards to evaluate potential associations between health outcomes and oil and gas development activity. Upstream activities include the transport of equipment and materials to and from the well pad, well drilling, mixing, handling, and injection of oil and gas chemicals; and management of recovered fluids/produced water, drill cuttings, and other waste products (Adgate et al., 2014; Johnston et al., 2019; NRC, 2014; Shonkoff et al., 2014). Sources of air pollutants include products of incomplete combustion and chemicals emitted directly and indirectly from surface and subsurface equipment including, but not limited to, wells, pumps, generators, compressors, pneumatic devices, storage and separator tanks, surface impoundments, solid and liquid waste handling and from venting and flaring of gases. Air pollutant emissions from upstream oil and gas development can include toxic air contaminants (TACs), criteria pollutants, and reactive organic gases which are associated with the formation of tropospheric ozone (i.e., smog).

Please note that air pollution and health impacts associated with midstream emissions (e.g., transmission pipelines and underground gas storage) and downstream emissions (e.g. emissions from refining and use of hydrocarbon products) were not considered in the CCST SB 4 Report (2015) or in this report. To apply this top-down approach, we draw from the peer-reviewed literature, where health hazards, risks and impacts of upstream oil and gas development are studied.

3.1. Study Inclusion Criteria and Approach

We extracted peer-reviewed studies published prior to 2015 that focus on air pollution, public health, and oil and gas development from the CCST SB 4 Report (2015). Peer-reviewed studies that were published prior to 2015 but were not discussed in the CCST SB 4 Report (2015) were beyond the scope of this review; however, we do note that there were approximately 25 health and 25 air quality original research studies published prior to 2015 (Shonkoff et al., 2015c). Four key studies discussed within the CCST SB 4 Report (2015) are included in Section 4.3.

We then searched scientific publication databases (Web of Science, PubMed and Google Scholar) using search terms (oilfield, oil field, oil drilling, oil and gas, natural gas, oil development, and gas development) AND (health, epidemiology, risk, hazard, air pollution, air quality) for *peer-reviewed* journal articles published after January 1, 2015. Finally, we extracted studies published between 2015 and 2018 from the PSE Healthy Energy Repository for Oil and Gas Energy Research (ROGER)[1], a near-exhaustive database of peer-reviewed literature on the impacts of shale and tight gas as well as other types oil and gas development (PSE Healthy Energy, 2018). Studies housed in ROGER are classified by impact category (e.g. climate, air quality, water quality, health, etc.). We conducted our last publication search on December 16th, 2018. Studies from the health and air quality impact categories were evaluated for inclusion in this assessment.

We included studies if they examined health hazards, risks, or impacts associated with air pollutants from upstream oil and gas activities in North America and were published in English. Government reports, environmental impact statements, white papers, law review articles, and other grey literature are not included in this assessment. Occupational health studies, while important, were outside the scope of this assessment and are not discussed explicitly. Air pollution studies were excluded if they lacked in-situ air quality measurements (e.g., studies that estimate emissions, but not impacts on air quality), examined regional rather than local air quality, or did not examine air pollution and exposure at specified distances.

Furthermore, health studies focused on factors of perception, subjective well-being, and mental health were not included (e.g., Hirsch et al., 2018; Maguire & Winters, 2017). The health literature also includes studies focused on other environmental stressors associated with oil and gas development, such as noise and light pollution and chemical exposure pathways through water. A relatively inclusive summary of this body of literature can be found in Hays and Shonkoff (2016). These studies were also outside of the scope of this review. We identified five studies focused on air pollution and health and 19 studies focused on public health outcomes published between 2015 and 2018 for inclusion in this assessment (Section 4.4, Figure 2).

[1] PSE Repository of Oil and Gas Energy Research (ROGER) Database can be accessed at: https://www.psehealthyenergy.org/our-work/shale-gas-research-library/

3.2. Approach to Calibration of Studies to City of Los Angeles Context

While there continues to be a dearth of epidemiological and other health investigations on oil and gas development in the State of California in general and the Los Angeles Basin in particular, an increasing number of these types of studies have assessed the health dimensions of oil and gas development in other parts of the United States and Canada. Each of the studies discussed in this review – as with any scientific study – has strengths and limitations in terms of study design, geographic focus, and causal inference. Some of the studies to date focus on shale gas and tight oil development enabled by high-volume hydraulic fracturing, which with few exceptions has not been deployed in the State of California and the Los Angeles Basin in particular. However, many of the studies published since January 2015 are relevant to the California and City of Los Angeles contexts given similar petroleum geology (e.g., migrated oil), technological approach to oil and gas production (e.g., enhanced oil recovery and other types of hydrocarbon production of migrated oil accumulations), density of oil and gas development, regulatory requirements (e.g., methane and non-methane volatile organic compound emission control rules), and maturity of oil and gas fields (e.g., presence of gas-gathering infrastructure and pipeline networks for water and hydrocarbon conveyance to reduce the need for trucking).

To further calibrate the results of the out of state studies to the City of Los Angeles context, we evaluated the human health hazards of chemical use in upstream oil and gas development as reported to South Coast Air Quality Management District (SCAQMD) pursuant to Rule 1148.2. This analysis can be found in the chemical assessment (Shonkoff et al., 2019b) in this larger report from the Office of Petroleum and Natural Gas Administration and Safety.

4.0. Review of the peer-reviewed literature on air pollution, human health, and oil and gas development

The results of our review of the literature are presented in the following sections:

1. **Summary of key public health findings from the CCST SB 4 Report (2015):** We review the key air quality and public health conclusions and recommendations from the CCST SB 4 Report (CCST, 2015).
2. **Studies that met our inclusion criteria for this review of the literature (2015 – 2018):** We depict the number of studies identified, screened, excluded, and included in this assessment.
3. **Review of air pollution and public health studies:** We summarize the peer-reviewed literature focused on air pollution associated with oil and gas development and health. These studies typically include local air monitoring efforts that contextualize findings in terms of human health hazard and risk through comparison of observed air pollution concentrations with health-based air quality reference concentrations and other standards.

4. **Review of public health outcome and epidemiological studies:** We summarize epidemiological research that estimates exposure using proximity to (or distance from) oil and gas development. Exposure metrics used in these studies often consider well density, temporally- and geographically-explicit well pad activities, and well productivity. While our primary focus is on studies that measure local-level exposures (e.g. by residence), studies that address exposures at a higher level (e.g. by zip code, county) are also discussed.
5. **Setback distance summary:** Peer-reviewed studies that discuss setback distances from oil and gas development are discussed. Existing setback distances in California and other states and localities are also presented.

4.1. Summary of key public health findings in the CCST SB 4 Report (2015)

The CCST SB 4 Report (2015) characterized emissions associated with oil and gas development in California, quantified populations in proximity to oil and gas development in California, summarized the environmental public health literature, and made an effort to calibrate findings from out-of-state studies to the California context. Direct and indirect impacts to air quality and human health were considered. The key principles, conclusions, and recommendations from the CCST SB 4 Report (2015) related to air quality and public health are presented verbatim in Table 1.

While the CCST SB 4 Report (2015) focused largely on issues of well stimulation (e.g. hydraulic fracturing, matrix acidizing and acid fracturing), a significant overarching conclusion of the report was that the majority of impacts associated with well stimulation are attributable to impacts of oil and gas development more generally. For example, air pollutants – such as benzene – may be emitted to the atmosphere during the relatively brief amount of time that hydraulic fracturing takes place, but emissions also occur, often in higher mass and rate during other phases of oil and gas development. Moreover, while benzene is sometimes reported as used as an additive in hydraulic fracturing fluids, emissions of benzene occur throughout the oil and gas development process due to the fact that the compound is co-produced with oil and gas and so the technological approach to hydrocarbon extraction – be it via hydraulic fracturing, steam injection or waterflooding – may not be as important from a toxic air pollutant exposure perspective.

Table 1. Principles, conclusions, and recommendations from the CCST SB 4 Report (2015) that consider air quality and public health.

Principle	Conclusion	Recommendation
Account for and manage both direct and indirect impacts of hydraulic fracturing and acid stimulation.	The majority of impacts associated with hydraulic fracturing are caused by the indirect impacts of oil and gas production enabled by the hydraulic fracturing.	Evaluate impacts of production for all oil and gas development, rather than just the portion of production enabled by well stimulation.
Understand and control emissions and their impact on environmental and human health.	Air pollutants and toxic air emissions[1] from hydraulic fracturing are mostly a small part of total emissions, but pollutants can be concentrated near production wells.	Control toxic air emissions from oil and gas production wells and measure their concentrations near production wells: Apply reduced-air-emission completion technologies to production wells, including stimulated wells, to limit direct emissions of air pollutants, as planned. Reassess opportunities for emission controls in general oil and gas operations to limit emissions. Improve specificity of inventories to allow better understanding of oil and gas emission sources. Conduct studies to improve our understanding of toxics concentrations near stimulated and un-stimulated wells
	Emissions concentrated near all oil and gas production could present health hazards to nearby communities in California.	Assess public health near oil and gas production. Conduct studies in California to assess public health as a function of proximity to all oil and gas development, not just stimulated wells, and develop policies such as science-based surface setbacks, to limit exposures.

4.2. Summary of toxic air contaminant findings in the Los Angeles Basin from the CCST SB 4 Report (2015)

Emissions of benzene and other toxic air contaminants (TACs) present well understood health hazards. Many TACs are co-produced with oil and gas development because of their natural occurrence in oil and gas reservoirs, regardless of whether hydraulic fracturing and other forms of well-stimulation are used (Garcia-Gonzales et al., 2019a). A previous assessment of California emissions inventories suggest that the upstream oil and gas development sector is likely

[1] Toxic air pollutants, also known as hazardous air pollutants, are those pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects. Criteria air contaminants (CAC), or criteria pollutants, are a set of air pollutants that cause smog, acid rain, and other health hazards (CCST, 2015).

responsible for a small fraction (<1%) of all criteria pollutants emitted in the South Coast Region of California (including Los Angeles), as this region is known for significant and diverse sources of emissions from mobile (cars, trucks and other transportation) and other industrial sources (Shonkoff et al., 2015b). However, as of 2014, emissions reported to emissions inventories suggest that 2,361 kg/year of benzene is emitted by the stationary components of upstream oil and gas development in the Los Angeles Basin, accounting for 9.6% of benzene emissions and 3.8% of formaldehyde emissions from all Los Angeles Basin *stationary* sources (Shonkoff et al. 2015b) (Table 2).

Benzene and formaldehyde emissions from oil and gas development represented a much smaller proportion (0.14% and 0.25%, respectively) of benzene emissions from *all* Los Angeles Basin sources (including mobile sources) due to the fact that the mobile sector is the predominant contributor of benzene emissions (Shonkoff et al. 2015b). Smaller proportions of other TAC species were identified (Table 2).

The proportion of reported TACs – with the exception of benzene and to a lesser extent, formaldehyde – attributable to upstream oil and gas development in the Los Angeles Basin has been reported as low. However, basin-wide fractions of emissions are less meaningful from a public health perspective than the mass of pollutants emitted, the timing and duration of emissions, and the geographic location of and proximity to human populations where emissions occur. While the spatial distribution of TAC emissions across Los Angeles oil and gas facilities are not known, what is known is that emissions of these TACs and other air pollutants from oil and gas development in the Los Angeles Basin occur in close proximity to human populations, including sensitive receptors such as schools, daycare centers, hospitals and elderly care facilities. Populations in close proximity to oil and gas development may be disproportionately exposed to associated emissions.

Table 2. Contribution of upstream oil and gas sources to TAC emissions in South Coast Region (kg/y) in 2010.

	Stationary oil and gas sources (kg/y) (2013)	Fraction of emissions from stationary sources	Emissions from all stationary and mobile sources (kg/y) (2010)	Fraction of all emissions from all sources (kg/y) (stationary and mobile)
1,3-Butadiene	56	1.60%	382,307	0.01%
Acetaldehyde	1	0.00%	1,352,128	0.00%
Benzene	2,381	6.60%	1,658,155	0.14%
Carbonyl sulfide	not available	not available	20	not available
Ethyl Benzene	28	0.50%	1,000,213	0.00%
Formaldehyde	5,846	3.80%	2,375,148	0.25%
Hexane	1	0.00%	1,608,303	0.00%
Hydrogen Sulfide	not available	not available	6,258	not available
Toluene	1	0.00%	6,860,168	0.00%
Xylenes (mixed)	1	0.00%	1,275,480	0.00%

Source: Shonkoff et al. (2015b)

As of 2015, in the Los Angeles Basin alone, approximately nearly 630,000 residents, 130 schools, 213 elderly facilities and 184 daycare facilities were sited, within a half-mile (2,625 ft) of an active oil and gas well. Of note, more than 32,000 people in the Los Angeles Basin are estimated to live within 100 meters (m) (328 ft) of an active oil and gas well (Shonkoff et al., 2015b) (Table 3).

Table 3. Numbers of residents and other sensitive receptors within various proximities of active oil and gas wells.

Buffer Distance (ft)	Buffer Distance (m)	Number of residents	Number of Schools	Number of Children Attending Schools	Number of Elderly Facilities	Number of Daycare Facilities	Under 5	Over 75
328	100	32,071	4	3,270	12	5	2,295	1,664
1,312	400	233,102	50	34,819	94	72	16,685	14,005
2,625	800	627,546	130	89,241	213	184	4,050	35,189
3,281	1,000	866,299	180	135,797	258	262	62,547	47,759
5,249	1,600	1,677,594	348	242,833	429	524	122,321	91,452
6,562	2,000	2,257,933	470	312,855	582	718	164,992	122,737

Source: Adapted from Shonkoff et al. (2015b)

Many in-situ monitoring and modeling studies estimate that emissions of health-damaging air pollutant species can be episodically elevated, leading to degraded air quality in proximity to and downwind from oil and gas development operations. For instance, Brown et al. (2015) modeled exposures between one and two kilometers (km) (3,281 - 6,562 ft) downwind of unconventional natural gas development and noted the variability across oil and gas development (shale gas development) phases by time (Figure 1). Brown et al. (2015) focused on shale gas and of course the development of this unconventional resource differs in many ways from the production of more shallow migrated oil and gas such as what occurs in the Los Angeles Basin. However, much of the infrastructure deployed for such activities are similar. All of the categories visualized below in Figure 1– flaring/finishing/compressor stations, and ongoing oil and gas production – are used in the Los Angeles Basin with often the exception of hydraulic fracturing, which is only used on a very limited basis in a small proportion of wells (Shonkoff et al., 2015b; DOGGR, 2019).

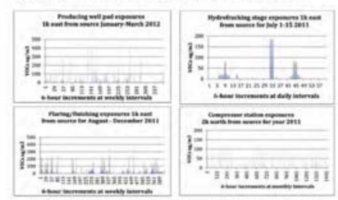


Figure 1. Intermittent spikes in volatile organic compounds (VOCs) during oil and gas development activities.
Source: Brown et al. (2015)

Many of constituents associated with oil and gas development can damage human health and place disproportionate risks on sensitive populations (e.g. children, pregnant women, the elderly) if they have significant enough exposures. Using California state emission inventories, Shonkoff et al. (2015b) found that oil and gas production in the San Joaquin Valley air district likely accounts for significant emissions of sulfur oxides (SOx), TACs such as benzene and hydrogen sulfide (H_2S). Oil and gas development accounted for a smaller proportion of total emissions in the Los Angeles

Basin (Table 2); however, larger and denser populations live, work, play and learn within close proximity of oil and gas development in this region, increasing the *intake fraction* of emissions that do occur.

The intake fraction is defined as the ratio of the mass of a pollutant inhaled or ingested to the mass of the pollutant emitted. As such, in the case of emissions of most pollutants to the air, intake fraction is the proportion of the total air pollutants emitted that are taken into the lungs of a human. The closer people are to oil and gas activities, the higher their potential exposure to air pollutants emitted from these facilities and the higher their risk of associated health effects and the larger the population, the larger the intake fraction. For a more in-depth discussion of intake fraction and its relevance to the South Coast region of California, please see Shonkoff et al. 2015b.

4.3. Summary of local air pollution and health studies and health outcome studies from the CCST SB 4 Report (2015)

Four key peer-reviewed studies were discussed in the CCST SB 4 Report (2015) regarding local air pollution and health or health outcomes associated with oil and gas activities. Considering community-level exposures, McKenzie et al. (2012) conducted air monitoring near oil and gas activities and proximal populations in Colorado. Using United States Environmental Protection Agency (US EPA) guidance to estimate chronic and sub-chronic non-cancer hazard indices (HIs) as well as cancer risks, the authors found that those living in closer geographical proximity to active oil and gas wells (≤ 2,640 ft) were at an increased risk of acute and sub-chronic respiratory, neurological, and reproductive health effects. Increased risk was driven primarily by exposure to trimethylbenzenes, xylenes, and aliphatic hydrocarbons; slightly elevated excess lifetime cancer risk estimates were also driven by benzene and aliphatic hydrocarbon exposure (McKenzie et al., 2012).

The findings of McKenzie et al. (2012) are in line with assumptions and calculations of atmospheric dilution data of conserved pollutants by the US EPA (1992). In 1992 the US EPA published a study on screening procedures for estimating the air quality impact of stationary sources. Using their assumptions, dilution of conserved TACs, such as benzene at 800 m (2,640 ft) is on the order of 0.1 mg/m^3 per g/s (US EPA, 1992). At 2,000 m (6,562 ft), dilution increases to 0.015 mg/m^3 per g/s and 0.007 mg/m^3 per g/s at 3,000 m (9,843 ft). Given that benzene poses an increased risk at a dilution of 0.1 mg/m^3 (estimated at $^1/_2$ mile, 2,640 ft), it is not certain, under these assumptions that atmospheric concentrations of benzene out to 2,000 m and 3,000 m (6,652 ft and 9,843 ft) can necessarily be considered low risk. However, beyond 3,000 m (9,843 ft), where concentrations fall more than two orders of magnitude via dilution relative to the $^1/_2$-mile radius, there is likely to be a sufficient margin of safety for a given point source. Of course, the health relevance of these estimates of atmospheric dilution strongly depend upon the mass and concentration of conserved pollutant emissions – such as benzene – that are emitted from a given stationary source.

In an oil and gas industry study in Texas, Bunch et al. (2014) compared volatile organic compound (VOC) concentration data from air monitors at six locations in the Barnett Shale with federal and state health-based air concentration values to determine possible acute and chronic health effects. The authors found that shale gas activities did not result in community-wide exposures to concentrations of VOCs at levels that would pose a health concern. Bunch et al. (2014), unlike McKenzie et al. (2012), used air quality data generated from monitors focused on *regional* atmospheric concentrations of pollutants in Texas, while McKenzie et al. (2012) included samples at the community level. Finer geographically scaled air sampling often captures local atmospheric concentrations that are more relevant to human exposure than sampling at the regional scale (Shonkoff et al., 2014). This observation may be driven by relatively steep gradients of conserved pollutants falling out of the atmosphere as they move away from their emission source.

Macey et al. (2014) analyzed air samples from locations in five different states using a community-based monitoring approach. Authors found that levels for eight volatile chemicals, including benzene, formaldehyde, hexane, and hydrogen sulfide, exceeded federal guidelines (ATSDR minimal risk levels (MRLs) (ATSDR, 2019) and US EPA Integrated Risk Information System (IRIS) cancer risk levels (USEPA 2017) in a number of instances. Self-reported data from a number of the residents who collected the samples reported a range of common health symptoms, including "headaches, dizziness or light-headedness, irritated, burning, or running nose, nausea, and sore or irritated throat" (Macey et al., 2014). The authors did not attempt to associate the reported health effects with the chemicals measured in the samples or seek verification of health symptoms by a physician. However, the study suggests that concentrations of air pollutants near oil and gas operations may be elevated to levels where health impacts could occur.

Health outcome studies published by the release of the CCST SB4 Report (2015) primarily used self-reported data as opposed to physician-reviewed and validated data (Rabinowitz et al., 2015; Steinzor et al., 2013). However, one peer-reviewed health study (McKenzie et al., 2014) is an exception to this trend. In a retrospective cohort study in Colorado, McKenzie et al. (2014) examined associations between maternal residential proximity and well density and perinatal outcomes. Risk for congenital heart defects in neonates was 30% (odds ratio [OR]: 1.3, (95% confidence interval [CI]: 1.2-1.5) greater among those born to mothers who lived in the highest density of gas development (> 125 wells per mile) compared to those with no wells within a 16 km (52,493 ft) radius of maternal residence. Babies born to mothers in the highest density of gas development had twice the odds (OR = 2.0, 95% CI: 1.0-3.9) of being born with neural tube defects than those born to mothers living with no wells within a 16-km (52,493 ft) radius (McKenzie et al., 2014). Exposure was negatively associated with preterm birth and a positive association of small magnitude was observed with fetal growth. No association was observed for oral clefts. The authors suggest that observed increased risk of neural tube defects and congenital heart disease with increasing density of gas development may be due increased atmospheric concentrations of benzene, a compound known to be associated with both of these conditions (Lupo et al., 2011). However, no air quality monitoring or field-based exposure assessment were included in this study, so the posited mechanism was not able to be directly verified.

While no peer-reviewed California-specific health studies were available for inclusion in the CCST SB 4 Report (2015), studies outside of California indicate that the most significant exposures to toxic air contaminants such as benzene, aliphatic hydrocarbons and hydrogen sulfide occur within ½ mile (2,640 ft) from active oil and gas development. Many of these compounds are co-produced from the hydrocarbon reservoir and co-emitted with oil and gas production. There is less certainty surrounding the potential for and impact of exposures to chemicals used for well stimulation and routine oil and gas development activities such as wellbore cleanouts, drilling, and routine well maintenance, further emphasizing the need to examine air quality and health risks associated with oil and gas development generally and not specifically around wells that have been hydraulically fractured.

4.4. Number of studies that met our inclusion criteria for this review of the literature published between 2015 – 2018

In the approach section of this report, we described our criteria for inclusion of studies published between 2015 and 2018 for further assessment in this report. In Figure 2 below, we show the numbers of studies that we initially found using our keywords across the study databases we searched and the number of studies that met our inclusion criteria and ended up included in this review. In the end, there were 24 peer-reviewed studies that met our criteria and were included in this study. We also included more studies on noise and oil and gas development, but these are separate from our systematic literature review on studies focused on air pollution and distance from and density of oil and gas development and public health.

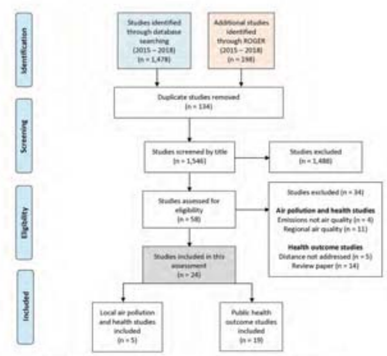


Figure 2. Decision tree to select studies that met our inclusion criteria for this 2015 – 2018 review.

4.5. Review of studies that investigate air pollution and distance from and density of oil and gas development and public health

As noted in the previous section, air pollution attributable to oil and gas development and its associated hazards and risks were evaluated in the CCST SB 4 Report (2015). In this section we discuss the peer-reviewed literature focused on local air pollution associated with upstream oil and gas development activities and published since 2015. Upstream activities include the transport of equipment and materials to and from the well pad; mixing, handling, and injection of oil and gas chemicals; and management of recovered fluids/produced water, drill cuttings, and other waste products (Johnston et al., 2019; Adgate et al., 2014; NRC, 2014). Sources of air pollutants include products of incomplete combustion and chemicals emitted directly and indirectly from surface and subsurface equipment including, but not limited to, wells, pumps, generators, compressors, pneumatic devices, storage and separator tanks, surface impoundments, solid and liquid waste handling and from venting and flaring of gases. Air pollutant emissions from upstream oil and gas development can include toxic air contaminants (TACs), criteria pollutants, and reactive organic gases which are associated with the formation of tropospheric ozone (i.e., smog). Chemicals known to be associated with oil and gas development pose acute and chronic health hazards, however health risks and impacts associated with these contaminants are dependent on the magnitude and duration of exposure.

While not always possible, in each reviewed study we note the geography, hydrocarbon resource being developed (e.g., oil or gas or both), the formation type (source rock/shale, migrated oil or gas, etc.) and the type of production technique employed (e.g., hydraulic fracturing, water flooding, steam injection, enhanced oil recovery, etc.). These specifications help to determine the applicability of a given study to the California context in general and the City of Los Angeles context in particular. Further, while practices and outcomes of each project are not available, we note the broad regulatory overlays of study location at the state level.

The environmental public health literature supports geographic proximity to active oil and gas development as an exposure and health impact risk factor. While oil and gas development contributes to regional air quality impacts (Allen, 2016; Halliday et al., 2016; Helmig, Thompson, Evans, & Park, 2014; Hildenbrand et al., 2016; Pétron et al., 2012; Pétron et al., 2014; Roy et al., 2014; Thompson et al., 2014) the majority of studies that assess air quality as a function of distance have observed that concentrations of various hazardous and other air pollutants can be even higher in close proximity to active oil and gas development (Brown et al., 2015; Brown et al., 2014; Colborn et al., 2014; Macey et al., 2014; McKenzie et al., 2012; McKenzie et al., 2018a; Rich & Orimoloye, 2016). The majority of studies that have assessed associations between oil and gas development and emissions of hazardous air pollutants (HAPs) have identified benzene, toluene, ethylbenzene and xylenes (BTEX), n-hexane, styrene, and 1,3 butadiene as emitted pollutants (Garcia-Gonzales et al., 2019a). The minority of studies, such as Bunch et al. (2014) did not find a positive correlation between proximity and air pollutant concentrations.

Intermittent spikes of emissions from oil and gas activities and equipment have also been observed (Allen, 2014; Brown et al., 2015), which may have a limited influence on regional air pollutant concentrations but are likely to be associated with increased exposures to populations in close proximity to emission sources. As such, studies that focus on regional concentrations of air pollutants associated with oil and gas development may arrive at estimates of low- to moderate-

level chronic exposures experienced by regional populations, but it is important to consider the proximity of receptors to sources to capture the range of potential public health risks (McKenzie et al., 2018a; Pétron et al., 2014; Shonkoff et al., 2015b).

Five studies have been published between 2015 – 2018 that characterize local exposures to nearby oil and gas activities using in-situ air monitoring. Paulik et al. (2016) deployed 23 passive air samplers in rural Ohio for three to four weeks to quantify polycyclic aromatic hydrocarbon (PAH) concentrations by distance to an active natural gas well pad. Sites were excluded if they were near other known sources of PAHs (e.g. airports, within city boundaries). Using PAH ratios, authors determined that PAH concentrations were from primarily petrogenic sources, as opposed to sources from combustion. As observed in other studies, health risk decreased with distance. Excess lifetime cancer risks associated with exposure to PAHs at sites closest to active wells (<328 ft) were estimated at 0.04 in one million, and decreased 30% at beyond 1 mile (5,280 ft) (0.027 in a million). Lifetime cancer risks observed were below US EPA upper threshold of one case per 10,000. Of note, passive sampling methods are useful to calculate average concentrations over deployment period, but do not characterize episodic spikes in emissions.

Paulik et al. (2018) used stationary passive samplers to characterize environmental exposure in conjunction with wearable silicone wristbands to estimate individual exposure to PAHs associated with nearby natural gas activities in Ohio. Thirty passive samplers were deployed near active (n=3) and proposed (n=2) natural gas sites at 55 to 122 m (180 – 400 ft) from the edge of the well pad, and silicone wristbands were given to participants living or working near the stationary sampling sites (n=19). Total PAH summation (ΣPAH) in air was significantly higher at active natural gas sites (Wilcoxon rank sum test, p<0.01) and was also more petrogenic at active sites as compared to proposed sites. ΣPAH detected using wristbands was significantly higher for participants within 0.75 km (2,461 ft) of an active well as compared to participants within 2-10 km (6,562- 32,808 ft) of an active well (Wilcoxon rank sum test, p < 0.005). Distance from participants home or work locations to nearest active well was significantly negatively correlated with ΣPAH detected by participants wristband (Pearson's correlation= -0.76, p=0.00010). Finally, there was a significant positive correlation between ΣPAH in participants' wristbands and ΣPAH in air measured closest to participants' homes or workplaces (simple linear regression, p < 0.0001). This study evaluated broad environmental exposure and individual exposure to PAHs associated with active natural gas sites, and found highest exposure correlated with closer distance using stationary and personal sampling devices. Participants completed exposure logs to identify additional sources of PAH exposure (e.g., cigarette smoke). However, while homes and workplaces were used as reference locations, exact time spent at reference locations was unknown. This work suggests that active natural gas sites emit PAHs into the air, and that living or working close to these sites may increase personal exposure to PAHs.

In Washington County, Pennsylvania, Maskrey et al. (2016) monitored for VOCs for three months at two locations near a single hydraulic fracturing well pad that had already been drilled. Monitoring sites included a school 863 m (2,831 ft) away and generally upwind of the well pad and a residence 774 m (2,539 ft) and generally downwind from the well pad. Authors monitored for total VOCs continuously and collected intermittent 24-hour integrated air samples for 62 individual VOCs. Monitoring occurred after the well was drilled, and during four activity periods, including an inactive period prior to fracturing, during hydraulic fracturing, during flaring, and another inactive period following fracturing. Total VOC concentrations in ambient air during well activity periods were similar to inactive periods. Furthermore, individual maximum 24-hr VOC concentrations did not exceed subchronic or chronic US EPA Regional Screening Levels. However, this study monitored air quality during limited activities at the well pad (hydraulic fracturing, flaring) and did not capture other activities associated with oil and gas development (e.g., drilling, flowback, emissions from tanks and separators). This study also focused on a single well pad, and is likely not representative of air quality impacts of many well pads in a given region.

In another recent study, McKenzie et al. (2018a) used in-situ air pollution monitoring to estimate exposure and calculate risk across an array of distances plausible for residential proximity established based on setbacks from surface property lines in Colorado. Monitoring the concentrations of air pollutants (such as benzene) at various distances from active oil and gas development operations, the authors found compelling evidence that cancer and non-cancer risks and impacts increase as distance between oil and gas development and residential proximity decreases. Most notably, the study found that within 152 m (~500 ft) of active oil and gas development, the cancer risk estimate was 8.3 cases per 10,000 individuals, exceeding the US EPA upper threshold for acceptable risk (1 case in 10,000) by 830%. The majority of the studies on the topic of distance from and density of oil and gas wells and public health to date have used distance and density as the exposure metric but have been criticized for not including actual in-situ air quality measurements. This study is notably stronger than previous work given that it includes in-situ air quality measurements that show compelling evidence that concentrations of some hazardous air pollutants (HAPs) are higher near oil and gas wells compared to further away. These findings also raise questions about existing minimum surface setback requirements in Colorado, and the effectiveness of state and federal regulations to protect the health of those living near oil and gas facilities.

Elevated benzene concentrations observed by McKenzie et al. (2018a) are also bolstered by a recent study that found that the concentration of benzene in raw natural and associated gas in Wyoming has a median concentration of 88.5 ppm and up to 330 ppm (DiGiulio and Jackson, 2016). Given that the majority of gas is captured for market or flared and the relatively steep gradient that heavier hydrocarbons such as benzene fall out of the atmosphere moving away from their emission source, these are not the concentrations that nearby and downwind communities

would likely be exposed to. However, these elevated source concentrations are important to consider when assessing hazard and risk of nearby populations. At this time there are limited publicly available data to adequately compare how benzene concentrations in California natural and associated gas resources compare to concentrations observed in Wyoming, given the dearth of publicly available data on benzene concentrations in gas produced from California oilfields. Nonetheless, intended and unintended venting, leaks, blowouts, subsurface stray gas migration and other emission events can result in benzene, a known human carcinogen, in the part per million (ppm) concentration to be emitted to the atmosphere. Emissions of certain pollutants, such as benzene at this concentration is certainly an occupational hazard (Esswein et al., 2014) and potentially a community hazard given that community health benchmarks of benzene exposure can be as low at 1 part per billion (ppb) (OEHHA, 2016).

Finally, McMullin et al. (2018) identified 56 VOCs emitted from oil and gas operations in Colorado and collated 47 existing air monitoring datasets in 34 locations in oil and gas regions. Authors aimed to characterize risk at and beyond 500 ft, and included air quality measurements that were collected between 350 and 3,700 ft from an oil and gas site. Authors found that acute and chronic non-cancer hazard quotients were not elevated for all individual VOCs, and hazard indices (HI) combining exposures for all VOCs were elevated for acute and chronic exposures (HI = 1.2 and 1.3, respectively). Similar to McKenzie et al. (2018a), the authors found lifetime excess cancer risk estimates for benzene were between 1 to 3.6 cases per 100,000 individuals and ethylbenzene was 7.3 cases per one million individuals. The lifetime excess cancer risk estimate for combined exposures was 4.3 cases per 100,000 individuals for distances between 500 ft and greater, exceeding the US EPA upper threshold for acceptable risk (1 case in 10,000). McMullin et al. (2018) lifetime excess cancer risk estimate also fell within the range reported by McKenzie et al. (2018a) for these same distances (1 case per 10,000 to 5.7 cases per 100,000).

4.6. Review of studies that investigate distance from and density of oil and gas development and associations with public health outcomes

While limited epidemiological data on oil and gas development and health has been collected in California, numerous epidemiological studies on this topic outside of California have been published. The health impacts evaluated by this body of literature include various health outcomes, including childhood and adult cancers, birth outcomes, upper and lower respiratory conditions, cardiovascular disease, fatigue, dermatological symptoms, migraines, sleep problems, and depression. In this section we discuss these 19 studies published between 2015 and 2018 in detail and present them organizationally by health outcome evaluated. Studies that use community-level exposure metrics (e.g. presence or absence of oil and gas development by zip code or county) are also discussed in this section. Most, but not all studies to date include distance from oil and gas development as at least part of the exposure metric considered. Studies that evaluate exposure using distance to oil and gas development are summarized in Table 4.

4.6.1. Cancer outcomes

A number of studies suggest that cancer risks increase with increasing proximity to oil and gas development (McKenzie et al., 2012; McKenzie et al., 2018a). Many studies posit, but do not confirm, that risks and incidence of hematological carcinogens, such as benzene, sourced from hydrocarbon reservoirs and co-emitted during oil and gas production are a likely mechanism (Garcia-Gonzales et al., 2019a).

McKenzie et al. (2017) investigated the potential association between residential proximity to and density of oil and gas development in rural Colorado and risk of hematologic (blood) cancers. Young individuals (ages 5-24) with acute lymphocytic leukemia (ALL) were over four times as likely to live in the highest well proximity and density category (<33.6 wells per 1.6 km, 5,249 ft) as compared to those not diagnosed with ALL [Odds ratio (OR): 4.3, 95% confidence interval (CI): 1.1-16.0]. A linear increase in risk of ALL was observed with increasing proximity and density exposure categories. No association was observed between proximity and well density for young children (ages 0-4) and for non-Hodgkin lymphoma. The authors cite exposure to benzene and other petroleum hydrocarbons in ambient air as well as elevated benzene concentrations detected in groundwater at oil and gas development sites in northeastern Colorado as potential environmental risk factors for childhood ALL. Furthermore, the researchers suspected that some limitations of this study may have biased the results toward the null, indicating that these findings may *underestimate* the true risk of hematologic cancer attributable to oil and gas development.

Another study in Pennsylvania showed the importance of considering legacy sources of pollution in an area experiencing oil and gas development. Finkel (2016) investigated unconventional natural gas development (UNGD) and cancer incidence in southwest Pennsylvania over time. Urinary bladder cases were higher than expected in counties with shale gas activity. Thyroid cancer cases increased over time, regardless of UNGD activity and patterns for leukemia incidence were mixed. Overall, observed cancer incidence was higher than expected prior to unconventional gas development in counties regardless of UNGD activity. While this study design is limited by county-level estimates of exposure, it makes the point that investigations into trends in cancer incidence associated with oil and gas development should take additional confounding factors, such a legacy pollution and the potential for synergistic toxic exposures into account.

4.6.2. Perinatal outcomes

A number of compounds associated with oil and gas development are associated with various perinatal outcomes (Balise et al., 2016; Webb et al., 2014). Four studies to date in Pennsylvania have focused on perinatal outcomes associated with natural gas development. Stacy et al. (2015) examined the association between proximity to UNGD in southwestern Pennsylvania and perinatal outcomes between 2007 and 2010. Inverse-distance weight well count within a mile – a measure

of distance and density – was used to estimate exposure. While no association was observed for premature birth, comparison between the most exposed (≥6 wells per mile, 5,280 ft) to least exposed (<0.87 wells per mile, 5,280 ft) revealed lower birth weight (3323 ± 558 grams vs 3344 ± 544 grams) and a 34% higher incidence of small for gestational age (OR: 1.34; 95% CI: 1.10–1.63).

In another study focused on Marcellus shale gas development in Pennsylvania, Casey et al. (2016) used an Unconventional Natural Gas Development (UNGD) activity index as the exposure metric. This exposure metric includes variables such as distance to maternal residence, dates and duration of well activities (spudding, production, etc.), and well characteristics (depth and production) during gestation. UNGD activity was associated with a 40% increased odds of a neonate being born preterm (fourth quartile: OR: 1.4, 95% CI: 1.0 – 1.9) as well as a 30% increase odds of high-risk pregnancies among the mothers (fourth vs. first quartile, OR: 1.3, 95% CI: 1.1 – 1.7). The authors did not observe associations between UNGD and Apgar score (an index measurement of newborn physical condition), babies born small for gestational age, or term birth weight.

In another study, Currie et al. (2017) reviewed over 1.1 million birth records prior to and during extensive hydrocarbon development in Pennsylvania. Authors compared births up to 15 km (49,213 ft) from hydrocarbon development and also compared siblings born before and during development. An association was observed between maternal residential proximity to active unconventional oil and gas wells and increased incidence of low-birth weight babies and declines in average birth weight. The most significant impacts on birth outcomes were observed within 1 km (3,281 ft) of unconventional oil and gas wells, while little evidence of health effects was observed at and beyond 3 km (9,843 ft).

In a retrospective study focused on Marcellus shale gas development, Hill (2018) evaluated adverse birth outcomes among babies born to mothers living near shale gas wells between 2003 and 2010. Introduction of drilling was associated with increased low birth weight ($p<0.05$) and decreased term birth weight ($p<0.01$) on average among babies born to mothers living within 2.5 km (8,202 ft) of a well as compared to mothers living within 2.5 km of a permitted, but not yet drilled, well. Singleton births (a birth of a single baby) to mothers living within 2.5 km of a well were also associated with small for gestation age (SGA) ($p<0.05$) and reduced Apgar scores ($p<0.05$), while no effects were observed for gestation or congenital anomalies. In an evaluation of well density, an additional well drilled within 2.5 km of maternal residence was associated with a 7 percent increase in low birth weight, a 5 g reduction in term birth weight, and a 3 percent increase in premature birth.

Two studies examined birth outcomes and UNGD in the Barnett Shale region of Texas in recent years. Whitworth et al. (2017), using a retrospective birth cohort study design, studied 158,894 women with a birth or fetal death from November 2010 to November 2012. The researchers evaluated correlations between poor birth outcomes and well-activity metrics that included inverse distance-weighted sum of active wells within three separate geographic buffers surrounding the maternal residence: ½, two, or ten-miles (2,640; 10,560; or 52,800 ft respectively. Women with zero wells ≤10 miles near them served as the largest buffer evaluated and served as the control group. A significant association was observed between distance/density and preterm birth across all three distances: ½ mile (2,640 ft) (OR: 1.14, 95% CI: 1.03-1.25), two miles (10,560 ft) (OR: 1.14, 1.07-1.22), and ten miles (52,800 ft) (OR 1.15, 1.08-1.22) and for fetal death at two and ten miles (OR: 1.56, 95% CI: 1.16-2.11; 1.34, 1.04-1.72). No significant association was observed for small for gestational age or term birth weight. These results suggest that there is an association between unconventional gas development activity and preterm birth and fetal death. A shortcoming of this study, like many others in the literature is that the study did not collect in-situ air and environmental samples to evaluate the incidence and magnitude of potential chemical stressors that may be the mechanism behind these observed associations.

In a case-control study, Whitworth et al. (2018) – using the same birth dataset as Whitworth et al. (2017) - estimated the effect of UNGD on birth outcomes in the Barnett Shale region of Northern Texas. This study was notably more rigorous and detailed than Whitworth et al. (2017) as it included more nuanced exposure metrics and parsed exposures by gestational age. The researchers individually age- and race/ethnicity-matched five controls to each pre-term birth case (n = 13,328) and divided the fetal time at risk according to the matched case's gestational age. The study included two phase-specific UNGD-activity metrics: (1) a simple IDW count of wells in the drilling phase ≤ ½ mile (2,640 ft) of the residence and (2) an integrated IDW sum of natural gas produced ≤ ½ mile (2,640 ft) of the residence. The researchers also constructed trimester- and gestation-specific metrics. Metrics were categorized as follows: zero wells (reference), first, second, third tertiles of UNGD activity. Analyses were repeated by pre-term birth severity: extreme, very, and moderate (<28, 28 to <32, and 32 to <37 completed weeks). The study estimated an increased odds of preterm birth in the third tertile of the UNGD drilling [OR = 1.20 [95% confidence interval (CI): 1.06, 1.37]] and UNGD-production [OR = 1.15 (1.05, 1.26)] metrics. Among women in the third tertile of UNGD-production, associations were strongest in trimesters one [OR = 1.18 (1.02, 1.37)] and two [OR = 1.14 (0.99, 1.31). The greatest risk was observed for extremely preterm birth [third tertile ORs: UNGD drilling, 2.00 (1.23, 3.24); UNGD production, 1.53 (1.03–2.27)]. While the magnitude differences in preterm birth are small, the results of this study suggest that UNGD is associated with preterm birth and that associations are strongest when exposures occur in early pregnancy.

In a retrospective cohort study in Oklahoma, Janitz et al. (2019) evaluated congenital abnormalities among 476,000 singleton births and proximity to natural gas activity. Authors considered well density and distance within two miles (10,560 ft) of maternal residence during the month of delivery. Authors observed an increased prevalence of neural tube defects and specific critical congenital heart defects among neonates both to mothers living within two miles of natural gas activity compared to mothers living with no wells within two miles. However, these findings were

not statistically significant. No association was observed for overall critical congenital heart defects or oral clefts (Janitz et al., 2019).

Biomonitoring, the collection of biological samples (e.g. blood, urine), can also be used to estimate individual exposure to contaminants. For pregnant women, biomonitoring can be used to characterize maternal exposure throughout fetal development. Caron-Beaudoin et al. (2018) detected developmental toxicants associated with oil and gas (e.g. benzene metabolites) in 29 pregnant women residing in unconventional gas producing areas of northeastern British Columbia (Canada). Benzene metabolites were detected at significantly higher concentrations in pregnant women living near gas development as compared to the general Canadian population (trans, trans-muconic acid concentrations, median = 180 ug/g creatinine; 10th percentile = 53.3; 95th percentile = 899). A significant shortcoming of this study is that although higher benzene metabolite concentrations were observed in the sampled population, source attribution is difficult given that this benzene metabolite is not specific to oil and gas development. A broader environmental assessment to rule out competing benzene exposures would be helpful to interpret the results in this study.

4.6.3. Cardiovascular and respiratory health outcomes and hospitalizations

Various peer-reviewed health studies have identified associations between oil and gas development and indicators of cardiovascular disease, respiratory outcomes (asthma and pneumonia), and hospitalizations for various health outcomes.

Only one peer-reviewed study has been published to date in California focusing on the Los Angeles region. Shamasunder et al. (2018) conducted household health surveys using questions from a validated health questionnaire (UCLA Center for Health Policy Research, 2016) within two 1,500 ft buffer areas surrounding the Jefferson and AllenCo oil production sites in the City Los Angeles. Physician-diagnosed asthma rates were elevated within both buffer zones compared to state-level and county-level surveys. Asthma prevalence was higher in one buffer zone (West Adams near the Jefferson drill site) than Los Angeles County. The study indicated that 45% of residents surveyed were reportedly unaware of nearby oil development. The study also included in situ air monitoring but only measured methane which may be a surrogate for non-methane VOC emissions from certain oil and gas infrastructure and processes, but there was no source apportionment and so the source of the methane is difficult to ascertain. To our knowledge, this is the most localized peer-reviewed assessment of asthma and oil and gas activities in the Los Angeles Basin. While this study compared localized asthma rates to state and county-level surveys, these comparisons do not take into account competing sources of air pollution – and other variables associated with asthma prevalence – and baseline demographic differences between these populations. It also relies on self-reported data, which can be difficult to interpret.

In a recent study in northeastern Colorado, McKenzie et al. (2018b) observed an association between the intensity of oil and gas activities and indications of cardiovascular disease. Using a cross-sectional study design (exposure and outcome evaluated at the same time), McKenzie et al. (2018b) recorded measurements of cardiovascular health and collected blood samples from approximately 100 adults in northeastern Colorado. The authors used an intensity adjusted inverse distance weighted exposure metric for wells within 16 km (52,493 ft) of each residence. This method allows for wells closest to each residence to contribute the most to that individual's exposure metric, unlike methods that use concentric buffers without adjustments for distance or intensity of activity. Greatest average plasma concentrations of systemic inflammation indicators were observed for those in the highest exposure group (>1,242 well intensity/km^2). Adjusted average augmentation index (a measure of arterial stiffness) differed by 6.0% (95% CI: 0.6-11.4%) and 5.1% (95% CI: -0.1 to 10.4%) between high and medium, respectively, and low exposure categories. For those not taking prescription medications, the adjusted average systolic blood pressure differed by 6 mmHg (95% CI: 0.1 to 13 mmHg) and 1 mmHg (95% CI: -6 to 8 mmHg) between the high and medium, respectively, and low exposure categories; no effect was observed for diastolic blood pressure. No association was observed with either systolic or diastolic blood pressure for those taking prescription medications. While these results suggest that there is an association between oil and gas activities and cardiovascular disease, this study was limited by its small sample size, its cross-sectional design, and its potential for confounding. Additionally, specific mechanisms of environmental stressors (e.g. air pollution or noise) were not evaluated. However, authors do note that inhalation of hydrocarbons has been associated with increases in cardiovascular emergency visits (Ye et al., 2017) and cardiovascular morbidity and mortality (Bard et al., 2014; Harrison, 2016; Villeneuve et al., 2013; Xu et al., 2009).

Numerous studies in Pennsylvania have investigated associations between patient hospitalizations and emergency room visits for respiratory and other health symptoms and UNGD in recent years. Jemielita et al. (2015) examined an association between unconventional gas wells and healthcare use by zip code from 2007 to 2011 across three northeastern counties. Cardiology inpatient prevalence rates were significantly positively associated with number of wells per zip code and wells per km^2 (3,281 ft^2), and neurology inpatient prevalence rates were significantly positively associated with wells per km^2 (3,281 ft^2). Evidence also supported an association between well density and inpatient prevalence rates for the medical categories of dermatology, neurology, oncology, and urology. These data may suggest that unconventional oil and gas development may be associated with increased inpatient prevalence rates within specific medical categories in Pennsylvania; however, these data may also indicate that unconventional oil and gas development disproportionately is sited in communities with higher existing disease burdens.

Willis et al. (2018) evaluated the association between UNGD and pediatric asthma hospitalizations in Pennsylvania between 2003 and 2014. The authors compared pediatric asthma hospitalizations among zip codes with and without UNGD activity, a community-level exposure metric including

drilling activity and air pollutant emissions reported by site. Odds of pediatric hospitalizations were consistently elevated in the highest exposure category compared to those unexposed. A 25% increase in odds of pediatric hospitalization for asthma was observed if a well was drilled within the same quarter (OR: 1.25, 95% CI: 1.07, 1.47). Presence of UNGD within the same zip code over the entire study period was also associated with an increased odds of pediatric asthma hospitalization 1.19 (95% CI: 1.04, 1.36). These results suggest that UNGD sites and associated air pollutant emissions are associated with increased risks of pediatric asthma hospitalizations. A potential alternative hypothesis could be that places with UNGD have become less attractive to live in overtime and thus wealthier and healthier people have moved away leaving a higher proportion of less healthy asthmatics.

In another study in Pennsylvania, Rasmussen et al. (2016) investigated the association between UNGD development and asthma exacerbations in Pennsylvania. Authors conducted a nested case-control study comparing asthmatic patients with and without asthma exacerbations between 2005 and 2012. Exposure was assigned on the day prior to the exacerbation or control date using activity metrics based on well phase (i.e., well pad development, drilling, stimulation, production) and distance from patients' home to well, well characteristics, and dates and durations of phases. Associations were observed between the highest quartile of activity metric for each phase compared with the lowest for nearly all exposure-outcome pairs. Exposure-outcome associations ranged from pad development and severe asthma exacerbations (OR: 1.5, (95% CI: 1.2-1.7) to production and mild asthma exacerbations (4.4, 3.8-5.2). This study provides compelling evidence that residential UNGD activities are associated with mild to severe asthma exacerbations that may require emergency room visits and/or hospitalization.

Koehler et al. (2018) used three UNGD exposure metrics to evaluate potential associations with mild asthma exacerbations in Pennsylvania. The authors compared two previous approaches (1) distance to nearest well drilled (<1 km, 1-2 km, >2km; <3,281, 3,281 – 6,562, >6,562 ft) and (2) an inverse distance metric based on the drilling phase (wells within 16 km, 52,493 ft); and a novel inverse distance-squared metric incorporating four phases of development (well pad development, drilling, stimulation, production) and compressor engine activities. Each UNGD exposure metric (highest exposure category compared to lowest) was associated with mild asthma exacerbations. Using previous methods and exposure categories, this study shows how different exposure metrics may yield similar findings.

Peng et al. (2018) also investigated the health impacts of UNGD of Marcellus shale in Pennsylvania between 2001 and 2013 by merging well permit data from the Pennsylvania Department of Environmental Protection with a database of all inpatient hospital admissions. Authors found a significant association between shale gas development (counties with unconventional wells) and hospitalizations for pneumonia among the elderly, which is consistent with higher levels of air pollution resulting from UNGD. The study is limited in that it relied on county-level exposure characteristics rather than focusing on residential distance to oil and gas wells.

4.6.4. *Additional health outcomes*

Numerous studies in Pennsylvania investigate broad health symptom reporting and psychosocial outcomes. While these studies focus on proximity, density, and well activity, mechanisms and exposure pathways are not specifically evaluated.

Tustin et al. (2016) investigated associations between UNGD and symptoms in a cross-sectional study in Pennsylvania. Using a self-administered standardized and validated questionnaire, the authors identified respondents with chronic rhinosinusitis (CRS), migraine headache, and fatigue symptoms. The authors then used an UNGD activity metric that incorporated well phase, location, total depth, daily gas production and inverse distance-squared to patient residences. Of respondents reporting two or three of the health outcomes, significant associations were observed between highest UNGD activity category compared to lowest for CRS and fatigue (OR: 1.88, 95% CI: 1.08-3.25), migraine and fatigue (1.95, 1.18-3.21) and all three outcomes (1.84, 1.08-3.14). Results indicate that UNGD activity was associated with acute health symptoms, such as nasal and sinus, migraine headache, and fatigue, in the sampled population. However, the authors note that the surveyed population oversampled patients with nasal and sinus symptoms; therefore, survey respondents may be sicker than the general population, limiting the generalizability of these findings.

Weinberger et al. (2017) reviewed records structured health assessments conducted between February 2012 and October 2015 retrospectively for 51 adults who lived within 1 km (3,281 ft) of a well across three southwestern Pennsylvania counties. Reported symptoms were reviewed by a physician, and symptoms were excluded if they could be explained by pre-existing conditions or those than began or worsened prior to exposure, measured by date of well drilling within 1 km (3,281 ft). Symptoms most commonly reported were: sleep disruption, headache, throat irritation, stress or anxiety, cough, shortness of breath, sinus problems, fatigue, nausea, and wheezing. While health studies using self-reported symptoms can be limited, this assessment included a critical review of symptoms for possible alternative causes through physician review, and confirmation of timing of exposure to unconventional natural gas well relative to symptom onset or exacerbation.

Finally, Casey et al. (2018) evaluated the association between UNGD in Pennsylvania and depression symptoms and disordered sleep diagnoses using a validated health questionnaire and electronic health data. Exposure (very low, low, medium, high) was assigned retrospectively based on residential proximity to wells, UNGD activity, and well characteristics. Depressive symptoms were associated with increased well density and larger wells. Using two models, high exposure (as compared to very low) was associated with depressive symptoms (exponentiated coefficient = 1.18, 95% CI: 1.04–1.34), and high and low (compared to very low) were also

associated with depression symptoms (High = 1.51, 95% CI 1.12–2.04; low = 1.63, 1.21–2.19). No association was observed for disordered sleep diagnoses. Authors note that the originally surveyed populations oversampled patients with nasal and sinus symptoms, and respondents may be sicker than the general population, limiting the generalizability of these findings. However, these findings suggest that UNGD may be associated with adverse mental health in a subset of Pennsylvanians.

4.6.5. *Noise associated with oil and gas development*

As discussed in the CCST SB 4 Report (2015), proximal populations experience disproportionate exposures to air pollution, noise, light associated with oil and gas development. While the assessment in this report has focused largely on air pollution, co-occurrence of multiple hazards from oil and gas activity readily occur and are important to consider. This section, separate from our systematic review, briefly summarizes the oil and gas development literature focused on proximity and noise.

Since the CCST SB 4 Report (2015), numerous additional studies have been published examining noise exposures (A- and C- weighted decibels, dBA and dBC) from oil and gas development and infrastructure near residential areas. A-weighted decibels (dBA) approximates the response of human hearing and is used for determining annoyance; C-weighted decibels are used to measure peak sound pressures when loud impulsive sources are expected (Wong, 2010).

Hays et al. (2017) reviewed the scientific literature on environmental noise exposure to determine the potential concerns, if any, that noise from oil and gas development activities present to public health. The authors found that data on noise levels associated with oil and gas development are limited, but measurements can be evaluated amidst the large body of epidemiology assessing the non-auditory effects of environmental noise exposure and established public health guidelines for community noise. The literature indicates that oil and gas activities produce noise at levels that may increase the risk of adverse health outcomes, including annoyance, sleep disturbance, and cardiovascular disease. More studies that investigate the relationships between noise exposure and human health risks from UOGD are warranted. Finally, policies and mitigation techniques that limit human exposure to noise from oil and gas operations should be considered to reduce health risks.

Radtke et al. (2017) monitored noise at oil and gas 23 sites in northern Colorado. At 350 ft, during three stages (drilling, hydraulic fracturing, and well completion) sites without noise barriers exceeded permissible noise levels for residential (55 dBA) and commercial (60 dBA) zones. Drilling and hydraulic fracturing sites with noise barriers also exceeded 55 dBA. At 107 m (350 ft) from the noise source, all drilling, hydraulic fracturing, and completion sites exceeded 65 dBC.

Boyle et al. (2017) evaluated noise from compressor stations used in oil and gas development and transmission that may pose risks to nearby communities in West Virginia. The authors found that noise levels exceeded both outdoor/daytime and indoor/nighttime US EPA decibel guidelines at homes less than 300 meters (985 ft) from a natural gas compressor station. Average indoor noise levels exceeded 40 A-weighted decibels (dBA), the level at which adverse health effects, such as sleep disturbance and insomnia, have been reported.

Another study, Blair et al. (2018), documented noise levels at a multi-well oil and gas well pad during construction and drilling in a residential area in Colorado over a 3-month period. Overall, 41.1% of daytime and 23.6% of nighttime dBA 1-min equivalent continuous noise measurements were found to exceed 50 dBA, and 97.5% of daytime and 98.3% of nighttime measurements were found to exceed 60 dBC. Measurements were taken within 320 - 550 m (1050 - 1805 ft) from the center of the well pad, exceeding the state regulatory setback distance (~152 m, 500 ft). Noise levels exceeding 50 dBA or 60 dBC may cause annoyance and be detrimental to health; thus, these noise levels have the potential to impact health and noise levels and associated health effects warrant further investigation. It would also be helpful for future studies like this one to help to characterize the extent to which their well pad and infrastructure samples are representative of these features more generally.

4.6.6. Summary of air pollution, noise, and health studies by distance

Studies are detailed by distance in Table 4. Increased risks from air pollution and elevated noise levels associated with adverse health outcomes have been observed in close proximity to oil and gas development. At 500 ft, the peer-reviewed literature suggests increased cancer risks (McKenzie et al., 2018a; McMullin et al. 2018) and elevated noise levels (Radke et al. 2017). Paulik et al. (2016) found no increased cancer risk at 500 ft, but the researchers only looked at PAHs rather than a wider array of pollutants identified in the literature. Elevated noise levels were also observed out to approximately 1,000 feet from compressor stations at levels at which adverse health effects, such as sleep disturbance and insomnia had been reported (Boyle et al. 2017). Furthermore, within 1,500-ft buffers around oil and gas sites in in Los Angeles, physician-diagnosed asthma rates were higher than state-level and county-level surveys. Asthma prevalence was also higher in a 1,500 ft buffer zone (West Adams near the Jefferson drill site) than Los Angeles County (Shamasunder et al. 2018). Additionally, a survey of experts determined that the minimum safe distance from unconventional oil and gas development is 1/4 mile (1,320 ft) and additional setbacks should be considered for vulnerable groups (Lewis et al. 2018; see Section 4.7).

Hazards, risks, and impacts attributable to oil and gas development are also observed in the peer-reviewed literature at 2,500 ft and beyond, including elevated noise levels (Blair et al. 2018), adverse birth outcomes (Currie et al. 2017; Hill et al. 2018; McKenzie et al. 2014; Stacy et al. 2015; Whitworth et al. 2017; Whitworth et al. 2018), increased non-cancer and cancer risks

(McKenzie et al. 2012), childhood cancer (McKenzie et al. 2017), and other acute adverse health outcomes (Weinberger et al. 2017). One peer-reviewed industry study (Maskrey et al. 2016) found that the maximum VOC concentrations did not exceed US EPA regional screening levels beyond 2,500 ft. However, numerous additional studies that have evaluated increased proximity, well density, and certain activities at the well pad have observed associations with adverse respiratory, cardiovascular, perinatal, mental health, and other acute health outcomes (Casey et al., 2016; Casey et al., 2018; Koehler et al., 2018; McKenzie et al., 2018b; Rasmussen et al., 2016; Tustin et al., 2016).

Table 4. Summary of health studies that estimate exposures to air pollution, noise, or other co-exposures as function of proximity to (or distance from) oil and gas development. Exposure metrics used may also incorporate well density, well pad activity. Studies are organized by distance evaluated and then alphabetically by lead author's last name.

Distance evaluated (ft)	Publication	Region	Reported primary hydrocarbon produced	Source rock, migrated hydrocarbons or both?	Study design	Study population and sample size	Findings	Health effect evaluated
≤500	McKenzie et al. (2018a)	CO	Oil and gas	Likely both	Air monitoring; risk assessment	467 1-hr samples of benzene, toluene, and C8 aromatics [illegible]	Within 152 m (~500 ft) of active oil and gas development, the cancer risk estimate was 8.3 cases per 10,000 individuals, exceeding the US EPA upper threshold for acceptable risk (1 case in 10,000).	Non-cancer and cancer risk
	McMullin et al. (2018)	CO	Oil and gas	Likely both	Risk assessment	Air quality data for 56 VOCs, across 47 datasets and 54 locations collected [illegible] from oil and gas sites.	Acute and chronic non-cancer hazard quotients were not elevated for any individual VOCs; hazard indices (HI) combining exposures for all VOCs were elevated for acute (HI=1.2) and chronic (HI=1.3) exposures. Lifetime excess cancer risk estimate for combined exposures was [illegible] cases per 100,000 individuals for 500 ft and beyond.	Non-cancer and cancer risk
	Paulik et al. (2016)	OH	Gas	Source rock	Air monitoring; risk assessment	23 passive air samplers monitoring for 62 polycyclic aromatic hydrocarbons (PAHs) over three to four weeks in 2014.	Within 0.1 km (~328 ft) of an active gas well, excess cancer risk estimate was [illegible] cases per 1,000,000, not exceeding the US EPA upper threshold for acceptable risk (1 case in 10,000).	Cancer risk
	Radtke et al. (2017)[a]	CO	Gas	Likely both	Noise – direct sampling	Four destinations used per site (27); 32 noise samples collected at 350 ft	At 350 ft, during three stages (drilling, hydraulic fracturing, and well completion) sites without noise barriers exceeded permissible noise levels for residential (55 dBA) and commercial (60 dBA) zones. Drilling and hydraulic fracturing sites with noise barriers also exceeded 55 dBA. At 350 ft from the noise source, all drilling, hydraulic fracturing, and completion sites exceeded 65 dBC.	Noise
≤1,000	Boyle et al. (2017)[a]	WV	Gas (compressor station)	N/A	Noise – direct sampling	Two (1 indoor and 1 outdoor) 24-hour measurements were collected at 8 homes [illegible] 3 homes [illegible] served as controls.	The authors found that noise levels exceeded both [illegible] US EPA decibel guidelines at homes less than [illegible] ft from a natural gas compressor station. Average indoor noise levels exceeded 40 A-weighted decibels (dBA), the level at which adverse health effects, such as sleep disturbance and insomnia, have been reported.	Noise
≤1,500	Shamasunder et al. (2018)	CA	Oil	Migrated	Self-reported survey	Surveys were collected at 205 randomly sampled residences within two 1,500 ft buffer areas surrounding oil development sites in City of Los Angeles.	Physician-diagnosed asthma rates were higher within two 1,500 ft buffer zones, as compared to state-level and county-level surveys. Asthma prevalence was higher in one buffer zone (West Adams) near the Jefferson drill site than Los Angeles county.	Respiratory
	Lewis et al. (2018)[a]	All	Oil and gas	Unknown	Survey (Delphi)	18 panelists (health care providers, public health practitioners, environmental advocates, and researchers) were surveyed; consensus was defined as agreement of ≥70% of panelists.	A survey of experts determined that the minimum safe distance from unconventional oil and gas development is ¼ mile (1,320 ft) and additional setbacks should be used for vulnerable groups.	General (health)
≤2,500	Hays et al. (2017)[a]	CO	Oil and gas	Unknown	Noise – direct sampling	Four residences sampled (continuous 1 min) for 1 – 2 months depending on location.	Noise measurements detected between 335 m (1,099 ft) and 550 m (1,805 ft) from the center of the well pad, show exceedances in daytime and nighttime dBA and dBC measurements that are associated with annoyance, sleep disturbance, cardiovascular impacts, and other health effects.	Noise
	Paulik et al. (2018)[a]	OH	Gas	Source rock	Exposure assessment	20 passive samplers across 5 active and 2 proposed natural gas sites; 19 wristbands supplied to participants living or working near stationary sampling sites. Sampling included 62 PAHs.	Measured PAH concentrations were significantly higher in ambient air and from personal silicone wristbands in close proximity to active gas wells (2,[illegible] ft), as compared to farther areas ([illegible] ft).	Exposure

Distance evaluated (ft)	Publication	Region	Reported primary hydrocarbon produced	Source rock, migrated hydrocarbons or both?	Study design	Study population and sample size	Findings	Health effect evaluated
[illegible]	Currie et al. (2017)	PA	Oil and gas	Source rock	Retrospective cohort	[illegible]	[illegible]	Perinatal
	Hill (2018)	PA	Gas	Source rock	Retrospective cohort	[illegible]	[illegible]	Perinatal
	Janitz et al. (2019)	OK	Gas	Unknown	Retrospective cohort	[illegible]	[illegible]	Perinatal
	Maskrey et al. (2016)	PA	Gas	Source rock	Air monitoring	[illegible]	[illegible]	Cancer and non-cancer risk

Distance evaluated (ft)	Publication	Region	Reported primary hydrocarbon produced	Source rock, migrated hydrocarbons or both?	Study design	Study population and sample size	Findings	Health effect evaluated
[illegible]	McKenzie et al. (2012)	CO	Gas	Likely both	Air monitoring; risk assessment	[illegible]	[illegible]	Non-cancer and cancer risk
	McKenzie et al. (2014)	CO	Gas	Likely both	Retrospective cohort	[illegible]	[illegible]	Perinatal
	McKenzie et al. (2017)	CO	Oil and gas	Likely both	Case-control (registry-based)	[illegible]	[illegible]	Cancer

Distance evaluated (ft)	Publication	Region	Reported primary hydrocarbon produced	Source rock, migrated hydrocarbons or both?[a]	Study design	Study population and sample size	Findings	Health effect evaluated
>2,500	Stacy et al. (2015)	PA	Gas	Source rock	Retrospective cohort	15,451 singleton births to women living in southwest Pennsylvania between 2007 and 2010	No association observed for premature birth. Lower birth weight and higher incidence of small for gestational age (SGA) observed with increased density of wells (≥6.07 wells vs. <6 wells per mile, 3,280 ft).	Perinatal
	Weinberger et al. (2017)	PA	Gas	Unknown	Retrospective survey (physician-reviewed)	135 structured health assessment records conducted between February 2012 and October 2015	Physician-reviewed symptoms reported within 1 km (3,281 ft) of active well drilling included sleep disruption, headache, throat irritation, stress or anxiety, cough, shortness of breath, sinus problems, fatigue, nausea and wheezing.	General (health)
	Whitworth et al. (2017)	TX	Gas	Source rock	Retrospective cohort	158,894 singleton births or fetal deaths to women living in the Barnett shale area between 2010 and 2012	Significant association was observed between distance/density of unconventional gas wells at 0.5 mile (2,640 ft) for preterm birth and fetal death at 2 miles (10,560 ft).	Perinatal
	Whitworth et al. (2018)	TX	Gas	Source rock	Case-control (registry-based)	163,037 singleton births to women living in the Barnett shale area between 2010 and 2012	Preterm birth was associated with increased proximity, density, and productivity of wells in the drilling phase within ½ mile (2,640 ft), with greatest association observed for women in the first trimester.	Perinatal
Combined exposure metric[f]	Casey et al. (2016)	PA	Gas	Source rock	Retrospective cohort	9,384 mothers linked to 10,946 neonates in the Geisinger health records from 2009-2013	Unconventional natural gas development (UNGD) activity was associated with preterm birth and physician-recorded high-risk pregnancy; no associations were observed for Apgar score, small for gestational age or term birth weight.	Perinatal
	Casey et al. (2018)	PA	Gas	Source rock	Retrospective cohort	4,762 participants with no (62%), mild (23%), moderate (10%), and moderately severe or severe (5%) depressive symptoms in 2014-2015 and 7,808 disordered sleep diagnoses between 2009-2015	Increased well density and larger wells were associated with depressive symptoms, but not disordered sleep.	Sleep/Depression
	Koehler et al. (2018)	PA	Gas	Source rock	Case-control	[illegible] cases and [illegible] controls using Geisinger health records	Using multiple UNGD activity metrics, UNGD was consistently associated with mild asthma exacerbations.	Respiratory
	McKenzie et al. (2019)	CO	Oil and gas	Likely both	Cross-sectional	Adults in northeastern Colorado (n=97)	UNGD activity was associated with indicators of cardiovascular disease (arterial stiffness, elevated blood pressure, systemic inflammation).	Cardiovascular
	Rasmussen et al. (2016)	PA	Gas	Source rock	Nested case-control	Patients with asthma aged 5 to 90 years (n=35,508) were identified in Geisinger health records	UNGD activity (pad development, drilling, stimulation, production) were associated with mild and severe asthma exacerbations.	General (health)
	Tustin et al. (2016)	PA	Gas	Source rock	Cross-sectional	7,785 adult patients of the Geisinger Clinic	UNGD activity was associated with chronic rhinosinusitis, migraine, and fatigue.	General (health)

[a] Determined by type of petroleum reservoir explicitly mentioned in the study; if not mentioned explicitly, we note the types of reservoirs produced from in the region or state in which the study took place.
[b] Studies evaluating noise levels near oil and gas development published since 2015, but not included in the systematic review.
[c] Study (discussed in Section 4.7) includes setback distance recommendations by health care providers, public health practitioners, environmental advocates, and researchers; health effects are not assessed.
[d] Exposure assessed at different scales (ambient air, personal exposure) and at gradient of distance; health effects are not assessed.
[e] Studies published prior to 2015 and discussed in the CCST SB 4 Report that evaluate air pollution and health effects by proximity to oil and gas wells.
[f] Studies using exposure metrics including multiple parameters, such as distance, density, activity at well pad, and well productivity.

4.7. Setback distances from oil and gas development and review of setback policies in the United States

A national spatial assessment of population proximity to oil and gas development found that 17.6 million Americans, including 2.1 million Californians, live within 1 mile (5,280 ft) of an active oil and/or gas well (Czolowski et al., 2017). Setback distances from oil and gas development can help mitigate proximal population exposures to air pollutants and other stressors associated with oil and gas activities that may be responsible for the observed human health risks and impacts in the peer-reviewed literature. Setback distances are typically established at the state or local level.

A few publications have discussed setback distances from oil and gas development and their associated effectiveness in reducing public health risks. Haley et al. (2016) investigated setback distances from unconventional oil and gas development in the Marcellus, Barnett, and Niobrara shale plays. In the areas studied, setback distances ranged from 150 to 1,500 ft. Given historical events and published modeling and air pollution data, the authors concluded that these existing setback distances do not appear sufficient to protect public health and safety from explosions, radiant heat, and air pollution from oil and gas development activities. Although the authors state that current legal setback distances are not adequate, no specific recommendations for setback distances are provided.

Lewis et al. (2018) surveyed a group of experts (researchers, scientists at government and regulatory agencies, and leaders in public policy and environmental advocacy) regarding safe distances from unconventional oil and gas development. Consensus (defined as agreement among 70% of participants) was reached determining that the minimum safe distance from unconventional oil and gas development is ¼ mile (1,320 ft) and additional setbacks should be used for settings where vulnerable groups are found, including schools, daycare centers, and hospitals. There was a lack of consensus around setback distances between ¼ - 2 miles (1,320 – 10,560 ft), due to limited health and exposure studies.

Webb et al. (2017) reviewed neurodevelopmental and neurological effects associated with chemicals used in unconventional oil and gas operations and the potential effects on infants and children. Upon review of Haley et al. (2016), the initial survey results presented in Lewis et al., (2018), and findings of McKenzie et al. (2012), Webb et al. (2017) recommended a setback distance of 1.6 km (5,249 ft) or greater for dwellings such as schools, hospitals, and other spaces where infants and children may frequent.

4.7.1. Review of setback policies in the United States

Existing setback distances for new development of oil and gas in the United States are summarized in Table 5. While California has no established statewide setback for oil and gas development,

local jurisdictions have established setbacks for residences and sites of sensitive receptors. Recently in California, the City of Arvin adopted an ordinance that establishes setback distances of 300 ft for new development and 600 ft for new drilling operations near sensitive sites, such as parks, hospitals, and schools (City of Arvin, 2018). In addition to localized setback distances, California Code of Regulation defines a critical well as within 300 ft of a residence or airport runway or within 100 ft of a dedicated public street, highway, or operating railway; any navigable body of water; any public recreational facility, or any other area of periodic high-density population, or any officially recognized wildlife preserve (State of California, 2011). The Division of Oil, Gas and Geothermal Resources (DOGGR) requires operators to disclose if a proposed well for drilling meets critical well (CA DOC, 2018), implying that wells in close proximity to populations may pose greater risk to public health and safety.

Table 5. Summary of minimum surface setback distances from oil and gas development in the United States. Updated from LACDPH (2018)[1]

State	Jurisdiction	Year Adopted	Setback Distance (ft)	Setback Target	Source
California	City of Arvin	2018	300	New Development	City of Arvin (2018)
			600	Sensitive sites, such as parks, hospitals, and schools	
	City of Carson	2015	750	Housing, schools, hospitals	LACDPH (2018)
	City of Los Angeles	2011	200	School, hospital, sanitarium, or assembly occupancy	City of Los Angeles (2011)
			50	Building (>400 ft² area, 36 ft tall)	
	Los Angeles County	2013	100	Building not necessary to the operation of a well	LA County Fire Department (2013)
			300	Place of assembly, institution, or school	
	Kern County	2015	210	Housing, schools, hospitals	LACDPH (2018)
	SCAQMD²	2015	1,500	Requires notification of nearby sensitive receptors (residences, schools, health care facilities)	SCAQMD Rule 1148.2 (2015)
Colorado	State	2013	500	Housing or commercial buildings	LACDPH (2018); Haley et al. (2016)
			1000	High occupancy buildings – schools, day care centers, hospitals, nursing homes, and correctional facilities)	Haley et al. (2016); (COGCC (2013)
			350	Outdoor recreational areas (playgrounds and sports fields)	Haley et al. 2016; COGCC (2013)
			150	Surface property line	Haley et al. (2016); COGCC (2013)
Maryland	State	2016	1,000	Housing, schools, faith institutions	LACDPH (2018)
			2,000	Private drinking water wells	

State	Jurisdiction	Year Adopted	Setback Distance (ft)	Setback Target	Source
New Mexico	Santa Fe County	2008	750	Housing, schools	LACDPH (2018)
			1,000	Groundwater and surface water resources	LACDPH (2018)
Oklahoma	Oklahoma City	2015	300	Housing, fresh water well	LACDPH (2018)
			600	Faith institutions	LACDPH (2018)
Pennsylvania	State	2012	500	Housing and commercial buildings	Haley et al. (2016)
Texas	City of Arlington	2011	200	Fresh water well	LACDPH (2018)
			600	Housing, schools, faith institutions, hospitals	
	City of Dallas	2013	1,500	Housing, schools, faith institutions	LACDPH (2018)
	City of Flower Mound	2011	1,500	Housing, schools, faith institutions, hospitals, existing water wells	LACDPH (2018)
	City of Fort Worth	2010	200	Fresh water well	LACDPH (2018)
			600	Housing, schools, faith institutions, hospitals	

[1] Setback table updated with information from the peer-reviewed literature and California county and city policies.
[2] Distance that requires notification of sensitive receptors, not a setback distance.

The California Air Resources Board (CARB) recommended that sensitive receptors should not be located less than 1,000 feet from a variety of industrial land uses and stationary sources of air pollutant emissions including distribution centers, rail yards and chrome platers (CARB 2005). The CARB also recommends that sensitive receptors should be located at least 50 to 300 feet away from gasoline dispensing facilities based on their size.

Of note, in Table 5, oil and gas operators in the SCAQMD are required – pursuant to SCAQMD Rule 1148.2 – to notify SCAQMD if an oil and gas well event (drilling, re-work, routine maintenance, hydraulic fracturing, etc.) occurs within 1,500 ft of a sensitive receptor such as a residence, school, hospital, or other health care facility (SCAQMD, 2015). A total of 597 (35%) oil and gas well events in the SCAQMD were located within 1,500 ft of sensitive receptors, of which 368 (62%) were within 600 ft of the receptor (Table 6, Shonkoff et al. 2019b). Within the City of Los Angeles, 106 out of 131 total events (81%) were located within 1,500 ft of a sensitive receptor and 81 out of 131 (62%) of the events were within 600 ft (Shonkoff et al. 2019b).

Table 6. Number of oil and gas well events with associated chemical use reported within 1,500 ft of a sensitive receptor in the SCAQMD.

Distance to Sensitive Receptor (ft)	All SCAQMD Events	City of LA Events
0-300	115	47
301-600	253	34
601-900	132	5
901-1,200	49	13
1,201-1,500	48	7
Total	**597**	**106**

Data Source: SCAQMD (2019)
Table Cited From: Shonkoff et al. (2019b)

5.0. Relevance of results in the peer-reviewed literature to oil and gas development and public health in the City of Los Angeles

As noted, the most rigorous and thorough way to evaluate the presence and magnitude of health risks and impacts associated with oil and gas development in California would be to conduct studies on oil and gas and public health in the within the State of California. Unfortunately, as noted, there is only one health study to date on oil and gas development and public health outcomes in California (Shamasunder et al., 2018) and it relies only on self-reported health outcomes data – a type of data that is very difficult to interpret.

Health studies published since July 2015 have assessed health hazards, risks and impacts including but not limited to childhood and adult cancers, upper and lower respiratory conditions, cardiovascular outcomes, birth outcomes, hypertension, fatigue, dermatological symptoms, and migraines. While there continues to be a dearth of epidemiological and other health investigations on oil and gas development conducted in California, an increasing number of studies have focused on these issues in other parts of the United States and Canada. Some of these studies to date focus on types of oil and gas development and regulatory regimes that are uncommon in California – such as shale gas development and coal bed methane production – however many of the studies published since July 2015 are relevant to the California context given similar types of regional petroleum geology (e.g., migrated oil) and methods of oil and gas development (e.g., enhanced oil recovery and hydraulic fracturing of migrated oil deposits).

As noted earlier, there are a number of variables to consider when trying to assess the applicability of a given study to the California context in general and the City of Los Angeles context in particular. Some of the main variables include the following:

(1) the type of petroleum reservoir (source rock vs. migrated hydrocarbons)
(2) the type of hydrocarbon under production (e.g., oil, gas, or oil and gas)
(3) the technological approach to hydrocarbon production (e.g., high volume hydraulic fracturing, water flooding, steam injection, etc.)
(4) The types and intensities of emissions of criteria and hazardous air pollutants
(5) the regulatory environment (e.g., qualitative rigor of emission control regulations)
(6) the density of oil and gas development
(7) the density and demographics of human populations near the oil and gas development under evaluation

In Table 4, a number of these variables are noted in order to help to illuminate the studies that are likely to be the most relevant to the California and City of Los Angeles contexts. The studies that take place in states and jurisdictions with similar attributes to the City of Los Angeles context are those that evaluate health hazards, risks and outcomes from *migrated* oil and gas development in states with relatively stringent air pollution emission control regulations. For instance, The State of Colorado produces oil and gas both from source rock as well as migrated oil and gas with the use of more shallow hydraulic fracturing and the application of enhanced oil recovery. Also, Colorado, like California, has a methane emissions control rule which – if properly enforced – may significantly reduce emissions of methane, non-methane VOCs and other air pollutants from certain types of infrastructure during upstream oil and gas development. Below we explore some of the similarities and differences between the oil and gas development context in the City of Los Angeles and studies from other parts of the country.

5.1. Petroleum Geology and Type of Oil and Gas Development

The majority of the studies that represent petroleum systems most similar to California were conducted in the State of Colorado which has, like California, a diversified petroleum geological system with significant migrated oil and gas development from shallower formations. Production of Colorado oil, especially that in higher permeability, shallower geological formations is often enabled with enhanced oil recovery (EOR) methods, much like in the City of Los Angeles. Waterflooding, a primary type of EOR, is deployed significantly in the Los Angeles Basin in general as well as in the City of Los Angeles. Furthermore, Colorado, like California has a methane emissions reduction rule which – if properly enforced – may significantly reduce emissions of VOCs and other air pollutants from certain infrastructure during upstream oil and gas development.

Studies that focus on air pollution and human health associated with the development of oil and gas from source rock – for instance shale wells in the Marcellus Shale region of Pennsylvania or the Bakken Shale region of North Dakota – may differ from studies that could be conducted in California or City of Los Angeles in a number of key ways. First, unlike many of the oilfields in

City of Los Angeles that have been in production for more than one hundred years, the development of shale gas in the Marcellus has only been at scale since the mid-2000s. The development of oil and gas in new areas often means that the gas-gathering and water movement infrastructure has not been built out to the degree that it is with mature oilfield operations, which can result in increased gas venting and the use of trucks for movement of water on and off site.

Of course, there are also similarities between oil and gas production in Pennsylvania and California. While in recent years unconventional oil and gas has dominated public conversation around well development, conventional well development in Pennsylvania is by no means obsolete. According to 2017 PADEP production records, 89.5% of all active Pennsylvania oil and gas wells are conventional (PADEP, 2018a; Hill et al., 2019). Over the years 2013 to 2017, 2,228 new conventional wells were spudded in Pennsylvania, making up 32% of all wells spudded during this time frame (PADEP, 2018b; Hill et al., 2019). Meanwhile, an increasing body of literature suggests that various hazards and risks are intrinsic to both types of hydrocarbon production (Jackson et al., 2014; Lauer et al., 2018; Stringfellow et al., 2017; Zammerilli et al., 2014). While most health studies in Pennsylvania are explicitly focused on shale gas development, few studies consider whether conventional oil production and associated infrastructure may be playing a role in their observations of air quality and health hazards, risks and impacts.

The lack of insight into the petroleum geology and hydrocarbon type under production is a frequent shortcoming of health studies on oil and gas development in the peer reviewed literature. For instance, as noted, Colorado has a very diverse petroleum geology with oil, natural gas, associated gas and condensate being produced from source rock as well as migrated accumulations in shallower geologies. In Colorado, there is are geographic and geological propensities for hydrocarbon type with oil being more prominently found in the Denver-Julesburg Basin – e.g., the region where the study by McKenzie et al. (2018a) was conducted – and natural gas being more prominent in the Piceance Basin – e.g., where the study by McKenzie et al. (2012) was conducted. Despite this shortcoming – or perhaps in light of it – it is notable that the majority of peer-reviewed studies on oil and gas development have found associated hazards, risks and/or impacts to human health (Hays & Shonkoff, 2016).

5.2. Differences in Air Pollution Monitoring

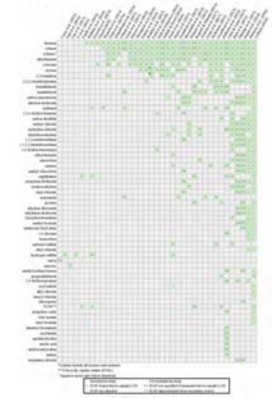
Given the use of exposure metrics (e.g., distance from and density of oil and gas development, volume of production of hydrocarbons, etc.) instead of in situ environmental measurements, it remains a challenge to determine which exposure or series of exposures may be driving the repeated observations of health impacts found in the peer-reviewed literature. While many of these studies posit that benzene and other air pollutants from oil and gas development activities may be driving these trends, the mechanisms of health impact remain uncertain. It is also possible that health impacts may be driven by pollutants that are not routinely monitored for, such as the volatile fraction of compounds used as additives in oil and gas development. The chapter in this report that assesses the SCAQMD 1148.2 database on chemicals used in oil and gas operations in the Los Angeles Basin, and City of Los Angeles in particular (Shonkoff et al. 2019b), evaluates what some of these compounds might be and what future air pollution monitoring efforts could expand their scope to focus on.

5.3. Overlap of types of pollutants emitted from the City of Los Angeles with those observed in the peer-reviewed literature

One way to compare the human health hazards of oil and gas development operations outside of the City of Los Angeles to those within the City of Los Angeles is to compare the types and intensities of emissions from the operations. As mentioned previously in this report, Garcia-Gonzales et al. (2019a) conducted a systematic review of peer-reviewed literature on hazardous air pollutants observed in emissions from and in the air near oil and gas development operations in the United States. The results of which HAPs were identified in the reviewed studies is shown below in Figure 3.

While there has been very limited in-situ air pollution monitoring around oil and gas development operations in the City of Los Angeles to date, the SCAQMD requires the reporting of toxic pollutant (many of which are HAPs) emissions from oil and gas operators in the State of California pursuant to The Air Toxics "Hot Spots" Information and Assessment Act (AB 2588, 1987, Connelly) enacted in 1987. The Hot Spots Program requires stationary sources to report the types and quantities of certain substances routinely released into the air. Many pollutants reported as emitted from oil and gas development pursuant to the Hot Spots Program to SCAQMD are also on the list of hazardous air pollutants observed at oil and gas operations nationally.

Figure 3. HAPs identified in studies from Garcia-Gonzales et al. (2019a).



[1] LOD: limit of detection

Source: Garcia-Gonzales et al. (2019a)

It is difficult to directly compare the mass and intensity of emissions of pollutants between operations in the City of Los Angeles and other operations in the United States for a number of reasons, including:

- Emission reporting requirements, if they exist are not uniform across states and regional jurisdictions.
- Emissions reporting to the SCAQMD are not the result of field-based measurements, but rather estimates based on assumptions regarding emission factors from equipment and the number of units of that equipment deployed.
- Emissions reporting to SCAQMD is not temporally explicit. For instance, reporting refers to pounds per year, but does not provide information on the intensity of emissions at any given time during the year.
- Emissions are reported to SCAQMD at the facility scale and geographically explicit information is not provided.

An in-depth comparison of pollutants observed in the peer-reviewed literature with chemicals reported to SCAQMD is beyond the scope of this report. However, available information on emissions of toxic pollutants and hazardous air pollutants suggest that the types of pollutants emitted from oil and gas development operations in the City of Los Angeles are similar to those emitted from operations in other parts of the United States where health hazards, risks and impacts have been observed in studies.

5.4. Density of Oil and Gas Development

While distance from oil and gas development is – across many of the peer-reviewed studies – associated with increased health risks and endpoints, the density of oil and gas development is also noted as a key factor. For instance, in Colorado, McKenzie et al. (2014) found that incidence of congenital heart defects and neural tube defects were associated with the highest exposure category (126 to 1,400 wells per square mile) as compared to the lowest exposure category (0 wells within 10 square miles). Similarly, in a case-control study, McKenzie et al. (2017) found that young individuals (ages 5-24) with acute lymphocytic lymphoma (ALL) were over four times as likely to live in the highest well proximity and density category (>33.6 wells per square mile) as compared to those not diagnosed with ALL. Additionally, a linear increase in risk of ALL was observed with increasing proximity and density exposure categories. In order to assess similarities in the oil and gas development context between the City of Los Angeles and studies that have assessed density of oil and gas wells as a proxy for exposure, we conducted a spatial analysis on density of oil and gas wells in The City of Los Angeles.

5.4.1. Approach to well and population density assessment in and around the City of Los Angeles

In the context of the City of Los Angeles, it is important to identify the particular neighborhoods and communities that host the most extensive oil and gas development to be able to appropriately put the density of oil and gas development in the City of Los Angeles in the context of findings of health outcome associations with oil and gas well density in the body of peer-reviewed literature. To assess oil and gas development density in a comparable fashion to what exists in the peer-reviewed literature, we used measures of the spatial density of oil and gas wells as a proxy for oil and gas activity. To do this we conducted a census tract cluster analysis to determine the well density in the most oil and gas well-dense regions of the City of Los Angeles and adjacent areas.

To conduct this analysis we used the 2012 census tract boundary file with 2017 tract-level demographics provided by ESRI, Inc (ESRI, 2019) dataset which provides current estimates based upon the most recent American Community Survey (ACS) 5-year data (2009-2017) (US Census Bureau, 2019). We then buffered these tracts at 1,000 feet, as per guidance of the California Air Resources Board for recommended separation of sensitive land uses from significant sources of air toxics and other health-threat air pollution (CARB, 2017) and calculated a "preliminary well density" metric for each tract that reflects the number of oil and gas wells within the tract buffer.[3] This analysis was conducted for the entire area of the City of Los Angeles, but includes wells near the city boundaries, as these add to the total impact of well density on a given census tract and its residents. The frequency distribution of this metric, countywide, was evaluated using the Jenk's Optimization procedure to identify a natural break at 10 wells per square kilometer. Because of the highly clustered nature of oil and gas wells in Los Angeles, tracts with values higher than this are adjacent, creating "clusters" of census tracts which define areas of the highest oil and gas well density in this region. These tract clusters, were for the most prominent Los Angeles neighborhood within their area, and a final well density metric was calculated to reflect the number of wells per square kilometer for the tract cluster. A variety of human population metrics are reported, below, reflecting aggregated values for each tract cluster.

5.4.2. Results of well and population density assessment in and around the City of Los Angeles

The tract clusters that represent neighborhoods with the highest well density in the City of Los Angeles and adjacent areas can be seen in Figure 4.

[3] Well data from DOGGR downloaded in March 2019; this analysis considers all wells described as either "active", "inactive" or "new"

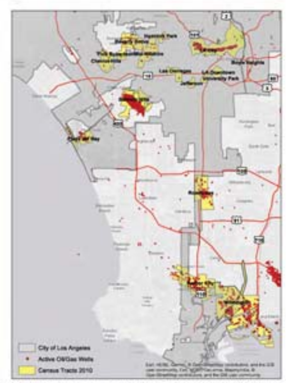


Figure 4. Clusters of census tracts (in yellow) named by neighborhood with the highest well density in the City of Los Angeles and adjacent areas. The dark-shaded portion marks the City of Los Angeles.
Source: Dr. James Sadd, Occidental College

In Table 7, we show the results of our analysis of oil and gas well and sensitive receptor density in neighborhoods within and near the City of Los Angeles. The highest well density in/near the City of Los Angeles is in the Baldwin Hills neighborhood which has 216 wells per square mile (83 wells per square kilometer). It should be noted that all of the wells near this neighborhood are located in unincorporated Los Angeles County. The highest well density within the City of Los Angeles is in the LA City Neighborhood (Koreatown, Westlake and Chinatown) with 162 wells per square mile (63 wells per square kilometer). Studies in the peer reviewed literature have found associations with poor birth outcomes, some childhood and adult cancers and other health outcomes at densities of 33.6 to 1,400 wells per square mile (13 to 540 wells per square kilometer). Using this range, 14 of the 15 tract cluster neighborhoods in the City of Los Angeles have oil and gas development (using oil and gas wells as a proxy) at the density associated with poor health outcomes in studies conducted in other parts of the country. In fact, density of oil and gas wells is in some cases higher per square mile in parts of the City of Los Angeles than the highest density category evaluated in studies in Colorado, Pennsylvania and Texas (Table 4).

Also of note in Table 7 is that the population density and demographics in the neighborhoods with high oil and gas well density. Population density is approximately 8,940 people per square mile (3,430 per square kilometer) throughout the City of Los Angeles and surrounding areas. The three highest population densities in high well density areas are found in the Jefferson (22,257 per square mile), University Park (22,237 per square mile) and LA City (Koreatown, Westlake, and Chinatown) (21,803 per square mile) neighborhoods. These population densities are much higher than those in rural Colorado, Pennsylvania and Texas where the majority of the peer-reviewed health studies have been undertaken. As such, while uncertainty exists as to how the emission profiles of oil and gas development in the City of Los Angeles compares to those in the studied areas in Colorado, Pennsylvania and Texas, what is clear is that emissions that do occur in the City of Los Angeles have a much higher intake fraction, i.e. the fraction of emissions that are inhaled by a human (Apte 2012, Marshall et al. 2003).

Table 7. Analysis of census tract clusters with the highest oil and gas well density within and near the City of Los Angeles, CA (Listed in order of well density)

Cluster	Tracts count	Wells count	Cluster land area	Cluster total area	Well Density	Well Density	Total population	Minority population	Total housing units	Owner-occupied housing units	Renter-occupied housing units	Median income
Baldwin Hills*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-

*Please note that wells in proximity to Baldwin Hills are located in unincorporated Los Angeles County

Source: Dr. James Sadd, Occidental College

6.0. Discussion and research and policy recommendations

We reviewed the peer-reviewed literature to assess the weight of the evidence surrounding whether oil and gas development is associated with human health hazards, risks and impacts. Our broad conclusion is that the literature published to date strongly suggests that there are health hazards, risks, and potential impacts to communities that live, work and play in close proximity to and among high density of oil and gas development. While the magnitude of health risks and impacts associated with oil and gas development in the City of Los Angeles is not extensively characterized there are enough similarities between the types of operations studied outside of California to operations located in the Los Angeles Basin that this body of literature should be carefully considered by regulators and policy decisionmakers. Moreover, the population density near oil and gas development in the City of Los Angeles is much higher than in most of the places where oil and gas has been studied and, as such, should also be a carefully considered in policy decisionmaking.

While not all of the peer-reviewed studies published to date are directly applicable to the City of Los Angeles, the body of science that is most relevant – predominantly from the State of Colorado – strongly suggests that public health risks and impacts increase as a function of density of and distance from, oil and gas development. Further, the density of wells in the primary oil and gas development areas of the City of Los Angeles is similar to those densities of wells that have been associated with poor health outcomes in multiple studies across multiple states in the peer-reviewed literature. While oil and gas well density does not answer questions about relative emission rates and intensities and other factors that may influence exposure, it is clear that multiple factors are similar between studied oil and gas areas and the City of Los Angeles context. Further, as noted, population density in the City of Los Angeles and surrounding areas is significantly higher than the majority of places studied in the peer-reviewed literature. While this fact should not influence the oil and gas development operations, it does suggest that any emissions that do occur in the City of Los Angeles could impact a far greater number of people.

The State of California and the SCAQMD in particular has taken important regulatory steps to control emissions from upstream oil and gas development. The CARB has been working to implement landmark methane control legislation that may also control some additional sources of non-methane VOC emissions and air districts have promulgated regulations to reduce VOC and NOx emissions from a variety of emission sources within upstream oil and gas development. However, simultaneously there are some key uncertainties and potential shortcomings of these state and regional regulations. For instance, approaches to methane control under the CARB methane rule may not control emissions from certain sources of non-methane volatile organic compounds (NMVOCs) and aromatic hydrocarbons such as those from oil flashing.

6.1. Emerging Field-Based Air Pollution Measurements Near Oil and Gas Development in the Los Angeles Basin

6.1.1. Mellqvist et al., 2017

While this report is a systematic review of the peer-reviewed literature, it is worth briefly discussing a recent report authored by the SCAQMD given its relevance to the City of Los Angeles. In an effort to characterize VOC emissions from stationary industrial sources (e.g., oil and gas wells, refineries, gas stations) in the South Coast Air Basin, SCAQMD supported FluxSense measurement projects using optical remote sensing methods (Mellqvist et al., 2017). The quantification effort included 5,000 active oil and gas wells across 17 sites in the Los Angeles Basin. Oil and gas wells were associated the following relative contributions of emissions sources assessed: 53% of alkane and benzene, toluene, ethylbenzene, and xylene (BTEX) emissions; 40% of BTEX emissions, and 46% of benzene emissions. Emission rates from oil and gas wells were estimated to be 6,510 kg/h of alkanes, 467 kg/hour of BTEX, and 75 kg/h of benzene emitted from oil and gas wells (138 kg/h of alkanes, 0.075 kg/h BTEX, and 0.012 kg/h benzene per well). The authors emphasize that given the substantial number of sources that are located close to residential neighborhoods, these results suggest that further investigation is needed to better quantify the impact of small sources to the overall BTEX emissions in the region (Mellqvist et al., 2017).

6.1.2. Garcia-Gonzales et al. (2019b)

In a recent effort to characterize pollutant decay by distance from oil and gas wells at the Jefferson drill site in the City of Los Angeles, Garcia-Gonzales et al. (2019b) monitored for air toxics (benzene and n-hexane) and an oil and gas tracer compounds (n-pentane) at 11 residential sites within 245 m (804 ft) of the closest wellhead. On the eastern transect, benzene and n-hexane were found to decay to background levels at approximately 130 m and 195 m (427 and 640 ft), respectively; n-pentane was detected at background level from 165 m (541 ft), but concentrations increased at the furthest sampling location. The opposite was observed at the western transect, where n-pentane concentrations decreased with distance and benzene and n-hexane concentrations increased with distance; authors note that the western transect was likely influenced by another upwind pollution source. Notably, n-hexane concentrations were elevated above background at approximately 200 m (656 ft) from the closest wellhead.

6.1.3. Study of Neighborhood Air Near Petroleum Sources (SNAPS)

Some remaining data gaps may be filled through the Study of Neighborhood Air near Petroleum Sources (SNAPS) program run by the CARB. The SNAPS program is tasked with measuring air

pollutant concentrations near oil and gas operations at the community level throughout the State of California.

The SNAPS program – if air quality data is collected in ways that appropriately captures the episodic nature of diverse emissions from upstream oil and gas systems – may provide important information for researchers, regulators and communities on questions surrounding human health risks associated with California oil and gas development activities. However, SNAPS is a single study and prudence should be exercised in over-extrapolating the validity of its results – positive or negative – to oil and gas development in general across temporal, geographical, geological, oil and gas operator and regulatory space in California. SNAPS results should be critically examined, compared against and integrated with results of other studies in the field, including those reviewed in this report.

6.2. The consideration of minimum surface setbacks to protect public health

The science is relatively clear that the development of oil and gas immediately adjacent to places where people live, work and play poses hazards and risks to public health and that some minimum distance from sensitive receptors should be considered. Texas, Pennsylvania, Colorado, New Mexico and other major oil and gas producing states have regulations that set a minimum surface setback requirement from sensitive receptors where oil and gas can be produced and in most cases these setback requirements are larger than those that exist in the City of Los Angeles and the State of California more generally.

The determination of how far is far enough is complex, especially given that much of the literature to date has also identified the *density* of oil and gas development to be a key factor associated with health risks. Nonetheless, analysis in this report has concluded that 14 of the 15 most oil and gas well-dense areas in the City of Los Angeles are at or above well density that has been associated with health hazards, risks and impacts in peer-reviewed studies from other parts of the country (see section 5.4).

LACDPH (2018) in their recent report provide helpful guidance with respect to recommendations for a setback policy in the City of Los Angeles. A summary of their assessment with respect to mitigation of health risks as a function of distance can be found below in Table 8 below. It should be noted that LACDPH reviewed Los Angeles County health complaints data and environmental impact statements in their assessment, yet included a more limited number of peer-reviewed air pollution and epidemiological studies than we did in this report.

Table 8. Mitigation of human health and emergency risks as a function of distance.

Setback Distance	Air Quality	Noise	Odors	Fires, Explosions, and Other Emergencies	Additional Mitigation and Assessment Notes
[illegible]					[illegible]
600 feet	✓				[illegible]
1,000 feet	✓	✓			[illegible]
1,500 feet	✓	✓	✓		[illegible]

✓ [illegible]

Source: LACDPH (2018), p. 22

As noted in Table 8, LACDPH (2018) asserts that concentrations of health-damaging air pollutants are expected to fall considerably around 600 ft from their emission source, but additional mitigation measures (e.g., heightened emission controls) should also be deployed as well as air pollution monitoring to screen for effectiveness. The LACDPH also concludes that most key public health and safety hazards would likely be mitigated at 1,500 ft from the emission source, with the exception of risks posed by fires, explosions and other emergencies.

The conclusions of the LACDPH (2018) report agree to a large degree with the findings in this literature review. The heavier and conserved air pollutants, such as benzene have a steep air concentration gradient as they move away from their emission source. However, as noted earlier, most of the studies that assess health risks and impacts as a function of distance in the peer-reviewed literature do not consider distances less than 2,500 ft due to the need for population sample sizes large enough to power their study and the majority – but not all – of these studies have found evidence of health impacts associated with oil and gas development at this distance.

Additionally, as noted in Shonkoff et al. (2019b), SCAQMD Rule 1148.2 requires reporting distance of oil and gas well events from sensitive receptors. Of note, 62% of oil and gas well events reported to this database between 2013 and 2018 in the City of Los Angeles occur within 600 ft of sensitive receptors. This may be important given that 40 (12%) chemicals reported to the SCAQMD dataset were identified on air pollution screening lists, of which 24 were used in the City of Los Angeles. A total of 22 chemicals were identified as hazardous air pollutants (HAPs) under the Clean Air Act, half of which were reported as used in the City of Los Angeles (Shonkoff et al. 2019b).

Recent published reviews of the literature (Johnston et al., 2019; Stacy, 2017) call for improved characterization of exposures by community health studies as vital to determine the full range of health risks to populations near oil and gas extraction. Given that it takes time to develop, implement, and publish peer-reviewed epidemiological research, strategies to mitigate community exposures should be undertaken. These approaches may include the implementation of minimum surface setbacks, emissions control technologies, caps on the number of oil and gas wells that can be sited per unit area, and other strategies (CCST, 2015). These types of exposure reduction strategies may be particularly beneficial in areas of high population density near dense oil and gas development, such as in the City of Los Angeles.

Below we list the key findings, conclusions and recommendations (FCR) that emerged from our assessment of the peer-reviewed literature.

6.3. Findings, Conclusions and Recommendations

Below we summarize our main findings, conclusions and recommendations (FCR) from this review of the literature and assessment of applicability to the City of Los Angeles Context.

FCR-1: Conduct studies in the State of California to assess the relationship between oil and gas development and public health as a function of distance.

Finding: Only one peer-reviewed oil and gas development and health study has been conducted in the State of California. There are however a variety of results and conclusions drawn from the greater peer-reviewed literature outside of California that are applicable to the California context.

Conclusion: There is a dearth of peer-reviewed studies on oil and gas development that are specific to the State of California and the City of Los Angeles, yet there are results and conclusions drawn from the weight of the peer-reviewed literature outside of California that are relevant to the California context.

Recommendations:

(1) Conduct health studies in the City of Los Angeles on the health dimensions of oil and gas development as a function of distance and oil and gas well density that incorporate multiple potential environmental and exposure pathways. These studies should assess active oil and gas development and could also include inactive oil and gas development such as plugged and abandoned wells and associated infrastructure. Given the increasingly expansive body of health literature on the topic, consider promulgating health-protective policies based on the existing literature.

(2) Ensure that field-based air pollution monitoring at the community scale and in close proximity to oil and gas development continues and expands and that it is implemented in ways that properly characterize emissions from these processes. This includes but is not limited to ensuring that air monitoring methods are deployed to capture the intermittent and periodic nature of emission events throughout the oil and gas development process and

that there is access to well pad-level activity information to inform the monitoring approaches.

FCR-2: Consider the implementation of a minimum surface setback requirement, caps on oil and gas development density and deployment of increased emission control strategies in the City of Los Angeles.

Finding: The majority of peer-reviewed studies that assess human health in the context of oil and gas development as a function of distance and density have noted increased hazards, risks and health impacts as distance decreases and density increases. The density of oil and gas development in oil and gas-producing neighborhoods in and near the City of Los Angeles is as high or higher than densities of oil and gas development associated with health impacts in out of state studies.

Conclusion: The development of oil and gas close to human populations poses higher risks of exposure to health-damaging air pollutants than the development of oil and gas further away from human populations. The same trend tends to exist for higher vs. lower density of oil and gas development.

Recommendations:

(1) Agencies with jurisdiction should consider the implementation of minimum surface setbacks between oil and gas development and sensitive receptors including but not limited to residences, schools and hospitals in the City of Los Angeles. The distance determined should, at a minimum, be far enough that heavier conserved air pollutants such as benzene have time to fall out of the atmosphere before reaching sensitive receptors. The decision as to how large the setback is should also take the available body of epidemiological studies into account. Studies to date conducted in regions with migrated hydrocarbon reservoirs have found associations with increased health risks associated with oil and gas development ranging from approximately 0.1 miles (500 feet) to one mile (5,290 feet). As such, a setback greater than 500 feet and up to 5,290 feet should be considered.

(2) Given that the *density* of oil and gas development has been found across a number of health studies to be associated with increased health risks, agencies with jurisdiction may consider limiting the density of wells and other oil and gas development infrastructure at oil and gas producing areas within and near the City of Los Angeles.

(3) Best available emission control technologies and management approaches should be deployed on all oil and gas wells and ancillary infrastructure to limit emissions of health-damaging air pollutants. Target air pollutants should include both those that are regularly monitored for (e.g., Criteria Air Pollutants, TACs and aromatic hydrocarbons such as benzene) as well as those pollutants that are less frequently monitored for including, but not limited to chemicals reported to SCAQMD pursuant to Rule 1148.2 that are known air pollutants.

7.0. References

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Exhibit 11 of 13 - SEI 2018. How Limiting Oil Production Could Help CA Climate Goals

SEI STOCKHOLM ENVIRONMENT INSTITUTE

DISCUSSION BRIEF

How limiting oil production could help California meet its climate goals

By many measures, the U.S. State of California has put in place climate policies that stand among the world's most ambitious. Over the last 15 years, the state has adopted (and extended) the nation's largest cap-and-trade program on greenhouse gases, stringent vehicle fuel efficiency standards, and strong urban planning guidelines. In 2018, it will hold a special climate summit for leaders around the world – with the support of Christiana Figueres, the former executive secretary of the United Nations Framework Convention on Climate Change (UNFCCC).

But even climate leaders like California will have to go well beyond existing actions to achieve the goals of the Paris Agreement – namely, keeping warming well below 2 degrees, plus reaching net zero emissions globally by the second half of the century. Indeed, in adopting its new climate action Scoping Plan in December 2017, California's Air Resources Board resolved to "continue to evaluate and explore opportunities to achieve significant cuts in greenhouse gas emissions from all sources, including supply-side opportunities to reduce production of energy sources."[1] In other words, the State has tasked itself not only to assess ways to increase the ambition of its climate action, but to consider how reducing energy production might also help achieve its climate goals.

This briefing paper examines how the state could limit the production of its principal energy product – oil – and the resulting implications for global GHG emissions. It also considers how such actions might fit in the state's climate portfolio, taking into account cost-effectiveness, equity, and other key considerations.

Though it is beginning to gain traction, limiting oil (or any fossil fuel) production is still relatively new as an element of jurisdictional climate strategies.[i] While there is less research available on the effectiveness and economics of reducing oil supply as compared with other GHG emission reduction strategies, there is nonetheless a sufficient body of theory and work to enable reasonable estimates, which we provide below.[3]

We find that restricting California oil production would likely decrease global GHG emissions by an amount similar to other key policies in the state's recently adopted climate Scoping Plan. We identify several policy approaches to limiting oil production that the state could consider with varying levels of emissions reductions, cost-effectiveness, equity implications, and political feasibility.[ii] These options range from stopping the issuance of new permits for

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Three pumpjacks move in synchrony as an oil worker looks on. They are located in the Kern River Oil Field outside Bakersfield, California.

oil production, to establishing thresholds for the GHG-intensity of oil produced, to focusing on regions of oil production where co-benefits, such as environmental justice, are greatest. These measures deserve further consideration by policy-makers in California.

California uses, produces, and refines a lot of oil

For most of the last century, oil has been central to California's economy. Californians long used more gasoline, diesel, and jet fuel in aggregate each year than any other U.S. state – a distinction only recently eclipsed, by Texas in 2014.[4] California has also been a dominant crude oil producer; for decades it was the top crude producer in the nation; it currently ranks third, behind Texas and North Dakota.[5] The vast majority of the crude extracted in California is consumed in-state, though some byproducts, such as petcoke, are exported to countries in Asia.[6]

Since 1990 – the base year for tracking California's climate change goals – the state's oil consumption has held relatively steady at between 600 million and 700 million barrels per year (Figure 1). Most of this oil is refined in-state and consumed as gasoline, diesel, and jet fuel. Together, burning of oil-derived products is the dominant contributor to California's carbon dioxide (CO_2) emissions (about 60%). Continued reliance on oil is a major reason why the state's CO_2 emissions have also held relatively steady, at between 300 and 350 million (metric) tons CO_2 for the past 25 years.[7] How oil consumption will evolve in the future is subject to economic, policy, and social developments in the state, including how quickly the state's residents adopt electric vehicles, a topic of intense current interest.[iii]

i For example, in 2016, President Obama cited climate change as a rationale for withdrawing the Arctic from oil exploration and development,[2] as did President Macron of France in 2017.

ii Note that we limit our focus here to oil extraction, and do not look at in-state oil refining.

iii Current reference-case forecasts by California state agencies and the U.S. Energy Information Administration indicate that, absent new, more-ambitious climate policy, California's oil consumption would hold fairly steady in the future. In these forecasts, continuous declines in gasoline use (e.g., dropping 3 to 4% each year) are foreseen to be offset by modest gains in diesel, jet fuel, and other oils (such as liquid petroleum gas, or LPG).[8,9,10]

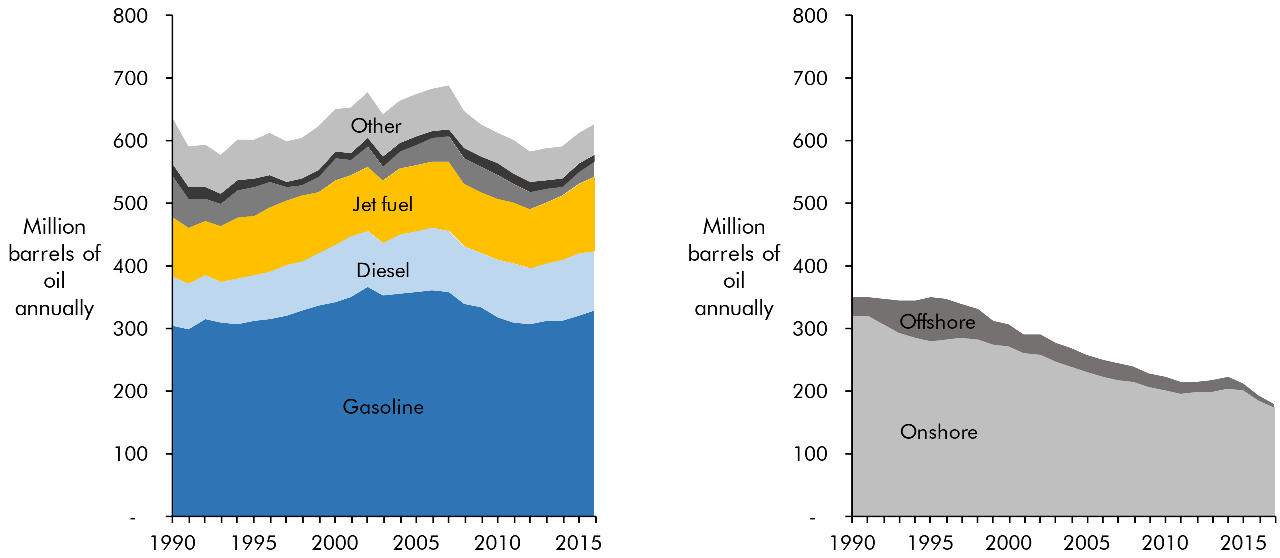


Figure 1: California oil consumption (left) and production (right) since 1990
Source: U.S. Energy Information Administration[4,11]

Even as oil consumption has held relatively steady since 1990, California's oil production has declined, by an annual average of about 2% since 1990. This is, in large part, because many of California's once-booming oil fields in the San Joaquin Valley – such as the Kern River and Midway-Sunset fields – are increasingly depleted.[12]

The outlook for oil production is perhaps even more uncertain than for consumption, as future oil drilling depends strongly on global oil prices and technology development in the oil industry, among other factors.[13] The U.S. Energy Information Administration estimates that California's oil production will continue to decline at between 2% and 3% annually through the mid-2030s.[14] Neither the California Energy Commission nor the Division of Oil, Gas, and Geothermal Resources (DOGGR) forecasts future oil extraction, but they do report on oil well permit applications, which have been robust. For example, DOGGR received more permit applications in 2015 than it has in decades.[15]

How would limiting oil *production* drop global CO_2 emissions?

To understand how limiting oil production could be part of a climate strategy, it helps to consider how oil contributes to greenhouse gas emissions. Each barrel of oil extracted in California (or anywhere else) contains carbon, that, once refined into products and burned, releases at least 400 kg of CO_2.[16,17]

Oil also contributes to greenhouse gas emissions as fossil fuel is combusted and CO_2 is released to extract, refine, and transport the oil; methane (CH_4) is also released during extraction. Together, these "upstream" emissions generally increase the lifecycle emissions from a barrel of oil to roughly 500 or 600 kg of CO_2 equivalent, depending on the nature of crude oil deposits and the technologies needed to extract and refine them (this is described later in Box 2).

Determining how limiting oil production in California would reduce GHG emissions is not quite as simple as tallying up the emissions associated with producing and combusting each barrel of oil produced, however. This is mainly because one must also look at the extent to which additional oil from other locations (or other energy resources) would make up for the lost California production, and therefore estimate the *net*, or *incremental*, reduction in oil production, consumption and emissions (plus increased production and use of other energy resources) that would result from the production cut.[3]

Removing California (or any other region's) oil from the market would cause a small increase in world oil prices, assuming a competitive global oil market (oil market dynamics are discussed in more detail in Box 1). This small price increase, in turn, would lead producers from other states or countries to produce somewhat more oil. At the same time, this small increase would lead consumers around the world to use slightly less oil. Widely used economic tools (price elasticities) enable these price-response dynamics to be modelled in a straightforward fashion.[18]

Using a simple economic model,[19,3] we estimate that, for each barrel of California oil *not* produced (left in the ground), an added 0.4 to 0.8 barrels would be produced elsewhere.

This yields a net reduction in global oil consumption of the inverse amount – between 0.6 and 0.2 barrels (1 minus the 0.4 to 0.8 above) for each barrel not produced – as consumers respond to the small price increase by making shifts in their vehicle purchases, driving habits, and other decisions. Most of these reductions would occur outside California, for the simple reason that California represents less than 1% of the global oil market.

The actual ratio of reduced oil consumption to oil not produced could be higher or lower than 0.2 to 0.6, but this range sits squarely within the broader range of existing literature, as summarized in Box 1. Notably, studies we reviewed by government (U.S. Department of Interior), think-tank (Council on Foreign Relations), private consultant (ICF), and university (UC Berkeley) researchers have all found ratios that cluster around a ratio of about 0.5, even as uncertainty exists.

Taking into account all but the outlier findings explored in Box 1 – that is, assuming a wide uncertainty range for this ratio of between 0.2 and 0.6 – it follows directly that for each barrel of oil left undeveloped in California, global oil consumption would be reduced by 0.2 to 0.6 barrels. Multiplying by the carbon content of crude oil noted above (400 kg CO_2/barrel), each barrel of oil not extracted from California would lead to a reduction in global emissions of 80 to 240 kg CO_2.

For illustration, phasing out an amount of oil equivalent to half of California's recent annual oil production – about 100 million barrels per year – could lead to a global emission reduction of 8 to 24 million tons CO_2 per year. This amount is similar to the savings associated with the sector-specific climate strategies in California's action plan, which range from 3 to 35 million tons CO_2e per year in 2030. Below, we identify some of the policies for managing a decline in oil production that the State may wish to consider in order to achieve additional emissions cuts of about this scale. First, however, we touch on cost-effectiveness and other considerations that State policy-makers may wish to take into account.

Still, before leaving the question of how reduced oil production would lead to emissions savings, it is worth noting the overall emissions benefit would be even greater to the extent that reduced oil consumption also leads to avoiding upstream GHG emissions, or those associated with *producing, transporting*, and *processing* that oil (See Box 2). At the same time, another effect could hamper the overall emissions benefit: the potential for consumers to substitute other GHG-emitting fuels, such as biofuels, compressed natural gas (CNG) or coal-fired electricity, for the oil not produced.

However, prior analysis suggests that the upstream emissions effect would likely be more significant than the fuel substitution effect, thus increasing by at least 25% the emissions savings per barrel of oil not extract-

Box 1: How restricting the supply of California oil reduces global oil consumption

At the most extreme end, if each barrel of oil not produced in California was instead produced somewhere else (and with similar emissions associated with extracting each barrel), then global emissions would not change at all – a game of "perfect substitution" or, as some have called it, "whack-a-mole".[20,21]

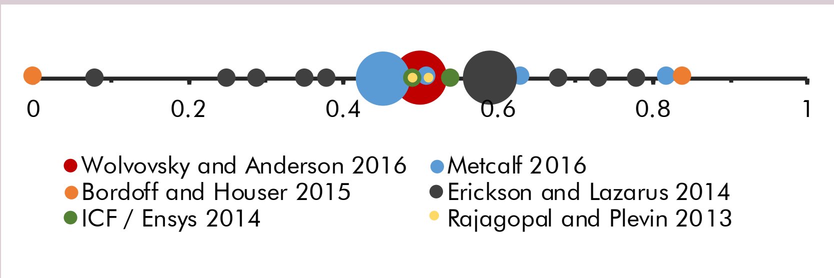
However, this argument of perfect substitution defies basic economics of supply and demand. If there is less of a commodity available – such as oil – less of it will be consumed. Exactly how much less is not knowable with absolute certainty, since the changes are moderated through markets and prices; still, the presence of uncertainty does not mean the effect does not exist.[22]

Here, we use a combination of literature review and our own simple economic model to estimate that for each barrel of oil not produced in California, global oil consumption would drop by 0.2 to 0.6 barrels.[3] This result is robust against a wide range of supply and demand elasticities. The 0.2 value would be consistent with an oil market with an elasticity of supply of 1 and an elasticity of demand of -0.25. Alternately, the ratio of 0.6 would be consistent with an elasticity of supply of 0.2 and an elasticity of demand of -0.3. (The ratio of change in consumption to change in oil supply is defined in our model as the ratio of the elasticity of demand to the difference between the elasticities of supply and demand. This means that any elasticities of supply and demand that are the same magnitude but opposite signs – indicating that both oil producer and consumers are similarly price-responsive – would yield a ratio of 0.5 barrels not consumed for each barrel not produced.[23,21])

Our estimate that global oil consumption would drop by 0.2 to 0.6 barrels for each barrel not produced is consistent with the findings of other assessments of the global oil market.[24,25,26,27] As shown in the chart below, several studies find a ratio near 0.5. The more far-ranging alternative outcomes – i.e., the ratios of less than 0.2 or over 0.6 – require particular views of the world oil market. For example, a scenario of zero impact on global oil consumption requires the very strong assumption that OPEC (or other producers) make up for every barrel of avoided U.S. oil production, one-for-one. This is despite evidence that OPEC has dramatically diminished ability to control production and, in turn, prices, through enforced production quotas.[28,29]

Drop in global oil consumption as fraction of avoided U.S. oil production across several studies

(Multiple circles of same color indicate alternate scenarios presented by same authors. Smaller circles represent sensitivity or high/low values)



Source: SEI analysis based on U.S. Department of Interior (Wolvovsky and Anderson 2016)[30] Council on Foreign Relations (Metcalf 2016)[31], Rhodium Group (Bordoff and Houser 2015)[24], SEI (Erickson and Lazarus 2014)[19], ICF/Ensys 2014[32] as included in Bordoff and Houser, and UC Berkeley (Rajagopal and Plevin 2013)[27]. The mean, median, and mode of results in this figure are all 0.5.

Box 2: Reducing oil production would lead to cuts in GHG emissions from extracting, refining, and transporting oil

Our estimate of the CO_2 emissions benefit of reducing California's oil production only counts the savings that would result from burning less oil, i.e. as gasoline, diesel, jet fuel, and other end uses in global fuel markets. However, were we to consider other GHG emissions associated with "upstream" (extracting) and "midstream" (refining and transporting) activities, the estimate of emission reductions could be greater.[19]

First, for each barrel of oil not consumed, emissions would be reduced by not producing, refining, and transporting crude oil. The exact decrease would depend on the likely marginal sources of crude oil. An average "blend" of crudes is associated with about 500 kg CO_2e per barrel across the full "life cycle".[33] Thus in addition to 400 kg CO_2 from fuel combustion, each barrel not consumed would save another 100 kg CO_2e in emissions.

Second, due to the widespread use of enhanced recovery techniques, such as energy-intensive steam flooding, California's most productive oil fields are more GHG emissions-intensive than the average blend of crude oil.[12] For example, the full life cycle of producing, refining, transporting, and combusting a barrel of crude oil from California's three most productive fields – Midway-Sunset, Kern River, and South Belridge – yields emissions of 725, 650, and 690 kg CO_2e, respectively.[33] For comparison, this is at least 15% more emissions-intensive than other crudes refined in California at similar volumes (at least 20 million barrels annually): Saudi Arabia (493 kg CO_2e); Ecuador (532 kg CO_2e); Alaska (564 kg CO_2e); Colombia (507 kg CO_2e); and Kuwait (510 kg CO_2e).[34] This means that reducing production of California oil would likely have global GHG emissions benefits, *regardless* of how much California production was replaced by other crude oils.

ed.[iv] For simplicity of the analysis, and to be conservative, we do not consider these effects in detail here. We do note, however, that even if *all* of the California oil not produced was replaced (globally) with other sources, there would still likely be emissions benefits, since California's largest oil fields are more GHG-emissions-intensive than most other global crudes (Box 2).

Limiting oil production is comparable in costs to many of California's other CO_2 reduction measures.

The analysis above demonstrates that phasing out oil supply from California could make significant contributions to global CO_2 emission reductions, barrel for barrel, and likely reduce global emissions by many millions of tons CO_2 in 2030.

Still, besides the amount of CO_2 emissions abatement, the Air Resources Board (ARB) also uses other criteria to gauge the merits of particular climate policies. One central criterion is cost-effectiveness. As applied by ARB and many other climate policy analysts, cost-effectiveness is defined as the net direct cost of a measure (amortized over its lifetime) divided by the emission reductions that would result from the measure.

It is not obvious how to assess the costs of a measure that would reduce emissions by constraining oil supply. One documented approach is to consider the costs of such a policy as the lost profits to the companies that would have extracted the oil.[35]

This approach – counting the costs of this climate policy measure as lost profits – is a clear analogue to how abatement costs are estimated for more traditional climate policies, such as for energy efficiency investments. In both cases, there is a change made to both an upfront investment as well as to a future cash flow stream, and the cost is determined as the amortized difference in costs between the new case (the change in investment or practice) and the old case (what would have happened otherwise).

For this reason, we apply a similar approach here. For a measure that would limit oil production, a company would forego the costs of drilling and pumping oil, but also forego the revenue of doing so. We therefore consider the direct "cost" of the climate policy to be the net of these two cash flow streams – i.e., the lost profits to the industry. This definition does not imply that the companies would be reimbursed for that cost – indeed, as with many other aspects of climate policy, the entities affected could be expected to bear those costs because of a societal duty to address the problem of climate change. Furthermore, this approach does not consider many other factors that could be included in a broader cost-benefit analysis, such as the avoided health impacts and other damages associated with CO_2 emissions, the potential for lost employment or tax revenues in an area, or other externalities.

Regardless, to estimate production costs, we start with estimates of the investment and operating costs associated with each California oil field. We draw this from a database of oil fields – Rystad Energy's UCube – that is widely used for analysis of oil resources and markets.[24,36]

Analysis of these cost estimates indicates that about one-third of California's oil fields are expected to "break even" at relatively low oil prices – e.g. less than \$50 per barrel. These include parts of the Lost Hills, Cymric, and Elk Hills oil fields, each of which is expected to produce at least 5 million barrels of oil in 2030 at below \$50 per barrel (Figure 2). Another third of California's oil breaks even at \$50 to \$70 per barrel, including the long-lived,

iv If we were to include both this fuel substitution effect and the upstream emissions effect, the net impact would be to increase our estimated range of emissions savings for each barrel of oil not extracted from 80 to 240 kg CO_2 up to 170 to 300 kg CO_2. For details on this calculation, see this online link: https://tinyurl.com/y7ue4dqp historic fields in Kern County (Midway-Sunset, Kern River) and fields in the Los Angeles area (Wilmington and Inglewood). Finally, the last, highest-cost third is dominated by newer fields (e.g. Monterey shale), plus older fields that are now being re-developed using newer technologies. That includes the South Belridge field, which is expected to be the dominant producer in 2030, yielding about 25 million barrels of oil, in part due to fracking.[5]

Comparing the breakeven prices displayed in Figure 2 – which are, essentially, the "cost" to these producers of drilling and operating new wells – with an estimate of future oil prices enables the calculation of future profits. In the EIA's reference case, for example, oil prices rise to $89 per barrel in 2030.[10] Subtracting the breakeven prices in Figure 2 from this 2030 price yields an estimate of potential lost profits, e.g. about $26 per barrel for the Wilmington, Inglewood, and Los Angeles fields.

This estimate of lost profits assumes an oil price, $89 per barrel, that is about one-third higher than levels of $60 to $70 per barrel in early 2018. This could very well be too high. In particular, if and as the world proceeds to rapidly displace oil-based vehicles with electric vehicles, to avoid vehicle travel, and to implement other policies – as California is doing – then oil prices may not rise significantly from current levels on a sustained basis. Under such a scenario of lower future oil prices, lost profits would be far lower; in fact, many fields might not yield the expected returns to investors, and could even operate at a loss. From that perspective, avoiding investment in new oil wells and associated infrastructure could help provide a net benefit to the industry (i.e., avoid financial 'stranding') as well as avoid locking in more oil production than needed.

Nonetheless, a measure of cost effectiveness can be calculated by dividing lost profits (as a proxy for costs) by the drop in global CO_2 emissions for each barrel not produced: 80 to 240 kg CO_2 as estimated above. For example, the cost-effectiveness of limiting California oil production from the Wilmington, Inglewood, and Los Angeles fields would be $110 to $330 per t CO_2 ($26 per barrel divided by 0.08 to 0.24 t CO_2 per barrel). Under a low-carbon future (i.e. one in which oil prices are closer to $60 per barrel, as also indicated in Figure 2), limiting oil production might instead even yield economic benefits, if the risks of stranded assets associated with investments in higher-cost fields, like South Belridge, are thereby avoided.

To put these costs in perspective, the cost-effectiveness of reductions in California's Scoping Plan range from "cost negative" (or yielding profits, as in the case of low-cost energy efficiency measures) to costs nearing $200 per t CO_2e. For example, the liquid biofuels measures associated with the Low Carbon Fuel Standard (LCFS) cost $150 per t CO_2e and a more aggressive renewable portfolio standard (RPS) for power supply cost $175 per t CO_2e.[8]

Equity and international considerations

The scale of GHG reductions and the cost-effectiveness of those reductions are just two criteria that policy-makers may need to consider in assessing potential climate policies. Other important considerations are environmental justice and equity. In fact, California legislation requires the consideration of equity in state climate policy; for example, state agencies have been directed (by the Global Warming Solutions Act of 2006) to identify and invest in disadvantaged communities. Equity is also a cornerstone of the international climate negotiations; further, policies seen as equitable can also be more *effective*. As described by the Intergovernmental Panel on Climate Change

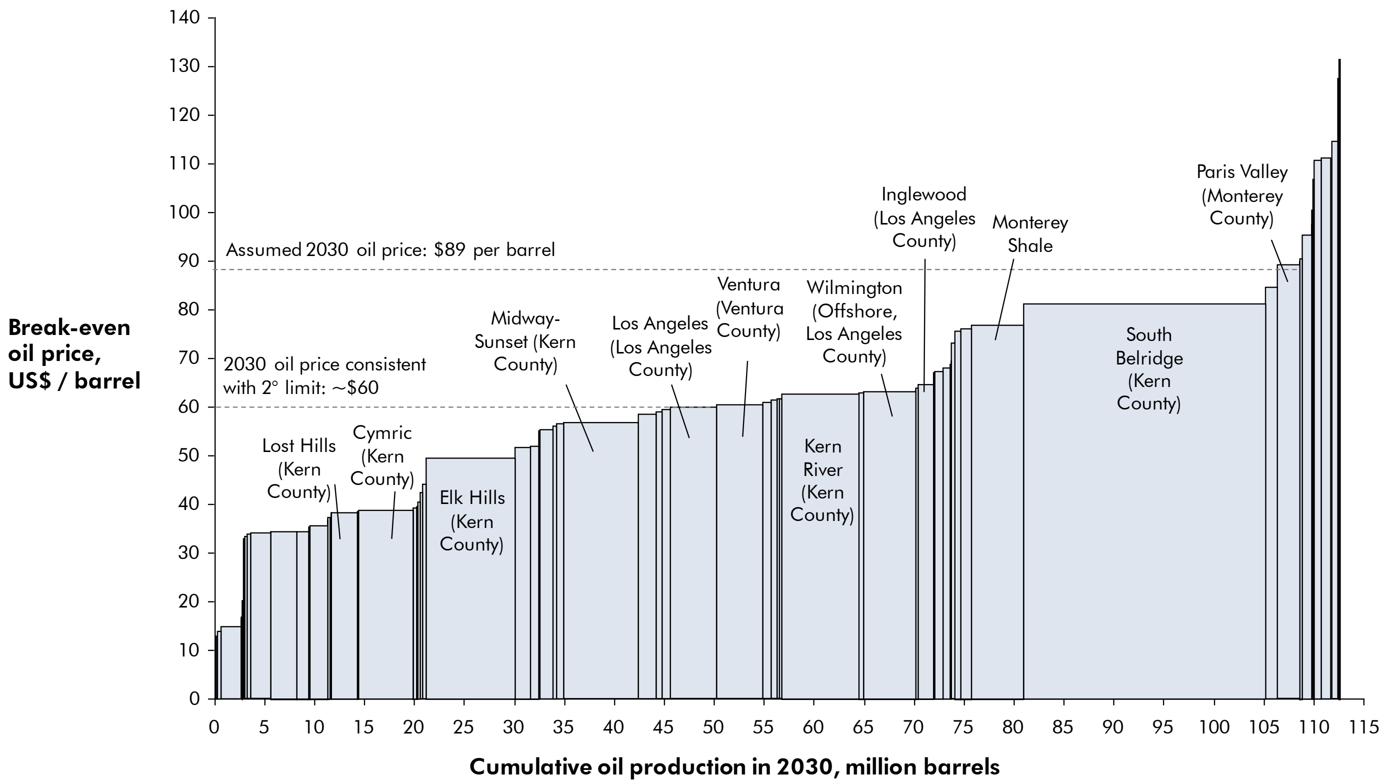


Figure 2: Cost curve for California's crude oil production in 2030

Source: Rystad Energy, assuming a 10% nominal discount rate.5

(IPCC), an "arrangement that is perceived to be fair has greater legitimacy and is more likely to be internationally agreed and domestically implemented."[37]

In this respect, phasing out California's oil production may also have an important contribution to make. This is because many of California's oil fields are located in areas of the state that are disproportionally burdened by pollution – both because of the presence of pollutants as well as due to adverse environmental conditions and socioeconomic factors.

For example, the oil fields in Los Angeles extend across communities that have been rated by the State's Office of Environmental Health Hazard Assessment as being among the census tracts that are most (95th percentile) disproportionately burdened in the State,[38] and where 630,000 people live within 800 meters (about 2,600 feet) of an active oil well.[39] The Lost Hills and South Belridge oil fields extend across communities – namely, the community of Lost Hills and neighbouring parts of unincorporated Kern County – that are in the worst fifth (80th percentile) of census tracts across the state in terms of pollution-vulnerability. These communities in Los Angeles and near Lost Hills may therefore be at greater risk for any possible health effects associated with proximity to oil (and gas) development.[40]

More broadly, limiting California oil production may have an even more basic benefit. It unambiguously moves in the direction needed to meet low-carbon goals: away from fossil fuels. This act of naming and addressing a major source of CO_2 emissions – oil – may also help build popular interest and support for a serious low-carbon transition.[41,42,43]

This support could also reasonably be extended beyond California's borders, as policy-makers in other states and countries with substantial oil supplies could take similar steps. As some economists have suggested, jurisdictions could even form a coalition of territories dedicated to phasing out fossil fuel production[44], thereby demonstrating the policy steps needed to realize the physical reality that, to keep global warming within the agreed goal of "well below" 2°C, most fossil fuel reserves will need to remain undeveloped.[45]

Gaining recognition for cuts to global, not just in-state, CO_2 emissions

How California would be recognized for emission reductions that result due to cuts in oil supply is another matter. Most of the emission reductions planned in California's Scoping Plan would accrue to California's official account –its *inventory* – of its GHG emissions. However, few of the cuts attributed to phasing out oil production would accrue to that inventory. This is because the bulk of those reductions would occur in other states and countries, as slightly higher global oil prices lead to lower oil consumption.

This accounting challenge, however, is a solvable problem. To address it, California could begin a complementary, parallel accounting, to track the estimated GHG emission reductions due to limits in oil production. Similar parallel accounting frameworks have already been proposed for the UNFCCC,[42] which is the forum – along with the IPCC – from which California modelled its own GHG emissions accounting.

Accounting for cuts to oil supply separately, in a report on emission reductions that are not captured by the state inventory, would also be a way to address the uncertainty associated with the global CO_2 emission reductions. For example, California could (1) specify the measure it is taking – e.g. stopping the permitting of new oil wells; (2) estimate how many barrels of oil would be left undeveloped as a result of the policy, and their associated total GHG emissions; and (3) estimate, with transparent assumptions, the *global* GHG emissions benefits of the action. These estimates could then be reported, shared, and subjected to international scrutiny, much like current, IPCC-based GHG emissions inventories.[v]

What policies could limit California's oil production?

So far, we have shown that limiting California's oil production could yield substantial additional emission reductions (e.g. 8 to 24 million tCO_2 per year in 2030 in the example above) at costs that are comparable to many other measures in the California Scoping Plan. In this section, we explore policy options that California could pursue to achieve these reductions and how they might align with other policy considerations and priorities.

Table 1 identifies and summarizes six discrete options for limiting oil production that California policy-makers could consider, noting the climate rationale, fraction of total state oil production that could be affected, feasibility, and other considerations. The first option is the simplest: California could stop issuing new oil well permits. If this measure were adopted, production would decline slowly as existing fields were depleted, and by 2030, it could drop by 60-70% relative to current and forecast levels. (The particular fields that would be most affected are explored in more detail below). The California Environmental Quality Act (CEQA) could provide the basis for DOGGR to deny permits based on their climate, health, and other environmental risks.

The State could also elect to restrict permitting of oil production in areas that already suffer from high pollution vulnerability. The California Council on Science and Technology, in its 2015 study of state-wide fracking and well stimulation, noted that the scientific literature supports the need for minimum distances between homes and oil wells -- called *setbacks* -- to limit exposure to air pollution from all oil and gas wells, and recommended that the state promptly implement setbacks and other measures to reduce exposure.[39,47] The State's Office of Environmental Health Hazard Assessment has also conducted an assessment of disproportionate pollution vulnerability for each census tract in the state that could be used to suggest where further oil production should be constrained.[38]

v CARB's Scoping Plan describes how the agency "has begun exploring how to build an accounting framework that also utilizes existing program data to better reflect the broader benefits of our policies that may be happening outside of the State." The emissions reductions that result from constraining oil supply could be addressed in such an accounting framework.

Table 1: Policy options for limiting oil production in California

Policy that would limit oil production	Climate rationale	Approximate fraction of California's oil production affected (in 2030)	Feasibility and other considerations
Cease issuance of new oil well permits	New oil wells are not consistent with Paris goals	~60-70%	New permits issued by DOGGR are subject to CEQA and may be denied based on their environmental risks and harms
Limit oil production in areas with disproportionate pollution vulnerability, e.g. using setbacks	Climate change already places disproportionate burdens on vulnerable communities	~40%, based on regions in the 80th percentile or more for pollution vulnerability	The CCST recommended that the state develop setbacks and other measures to limit exposure to air pollution from oil and gas wells
Charge a carbon 'adder' on oil extraction	A carbon adder could be charged at the wellhead to cover a portion (e.g. 50%) of the damages associated with burning each barrel of oil, similar to CEA 2016[46]	~25% would no longer be economic, based on adder equivalent to \$50/tCO_2 or ~ \$20/bbl and oil price of \$89/bbl	Could be structured as a severance tax or similar fee and provide revenue for a just transition away from fossil fuel extraction
Remove state-level subsidies (or counteract existing federal subsidies) for oil production	Subsidies, including U.S. federal tax preferences, increase oil production (and profits), increasing emissions	Up to 50%[36]	Would require defining in-state subsidies and a detailed understanding of field or well cost data, usually proprietary
Phase out GHG-intensive oil production through an emissions performance standard (e.g., total life cycle GHG emissions cannot exceed 600 kg CO_2e/barrel)	Maximizes overall GHG savings per barrel not produced; achieves some emissions reductions regardless of level of substitution	~70-80% is from fields currently > 600 kg CO_2e/bbl	Requires estimates of GHG-intensity for each oil field; could lead to on-site emissions mitigation measures instead of reduced production
Phase out high-cost oil (e.g., oil that requires a breakeven price of \$60 per barrel or greater without subsidies[3])	Better aligns CA oil production with 2 degree target; reduces risk of stranded assets as high-cost oil may not be financially viable in a low-carbon transition	~40%	Requires understanding of field or well-level cost data, usually proprietary and subject to change with technology advancement over time

Another option would be to place a carbon adder or price on the carbon in oil that is extracted, which could be implemented in the form of a severance tax (which many states apply), and could be used to support transitions for workers and communities more dependent on oil. This type of approach was assessed (for coal) by the White House Council of Economic Advisors in 2016 and could apply similarly to oil.[48,46]

The State could also choose to create thresholds or criteria for issuing new permits or for continued operations. The State could implement an emissions performance standard for oil production – by requiring producers, for example, to limit emissions to 600 kg CO_2e per barrel. This would be similar to its Low Carbon Fuel Standard (by incorporating full life cycle emissions) and its Emissions Performance Standard for power plants.

An emissions performance standard, however could result in fewer GHG emission reductions if it doesn't stop production – and instead encourages producers to take more modest steps to reduce the GHG-intensity of production to just below the threshold. For example, the large South Belridge field could reduce emissions-intensity of each of its barrels from an estimated 690 kg CO_2e to 600 kg CO_2e, achieving a 90 kg CO_2e reduction per barrel. But ceasing production would reduce those emissions by at least that much, *plus* 80 kg to 240 kg per barrel from reduced oil consumption.

Another type of threshold – a cost-based threshold – would help make future investment and production more consistent with global climate goals and reduce the risks of stranded assets. For example, research has indicated that the price of oil could be in the range of \$60 per barrel or less in an economy where oil demand is reduced to levels consistent with a 2-degree warming goal, suggesting that new oil fields or wells that break even above this level may become 'stranded'.[3]

As Table 1 and this discussion illustrates, there are a number of practical measures that State decision-makers could consider as part of integrating limits on oil production in its overall climate strategy. In doing so, the further examination of key implications – from the cost and feasibility to interactions with other California policies such as the cap-and-trade program – would be valuable.

Illustrating how a phase-out of permitting might work

In this section, we explore the option of phasing out new well permits in more detail. Figure 3 displays a scenario of how these new permits – about 2,500 issued each year – determine the state's future oil production. In this figure, the state's total oil production is taken from U.S. EIA's reference case scenario that already sees California oil production declining steadily, as stated above. We then assume that production from already operating wells declines at 10% per year (based on well-specific data available in the Drillinginfo database), and that the

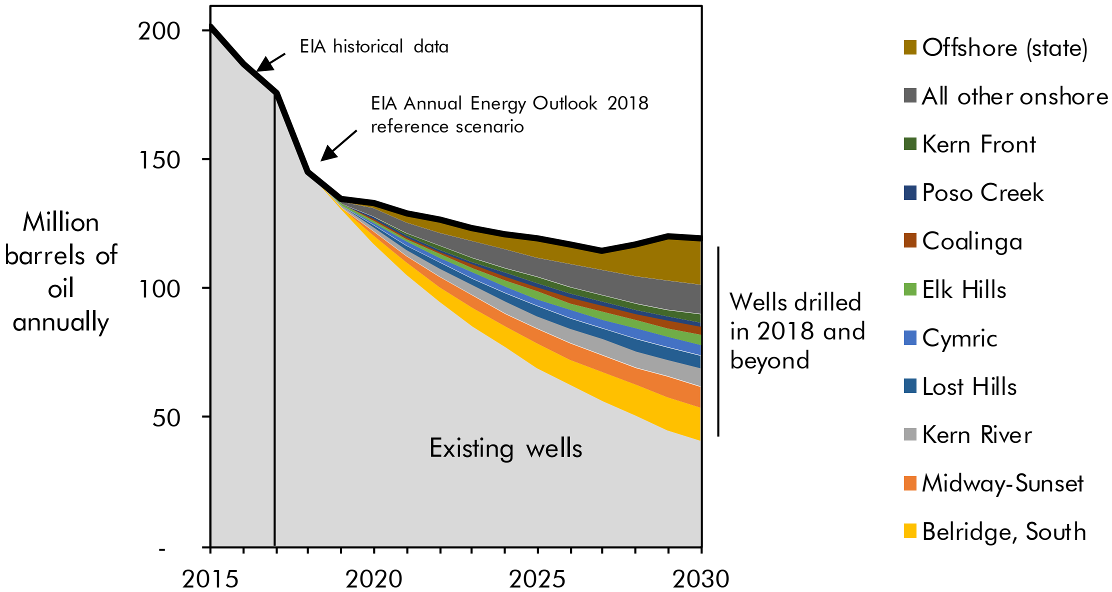


Figure 3: Scenario of California's future oil production

Source: EIA Annual Energy Outlook 2018 (top line, reference case oil production); Drillinginfo database (decline rate for existing wells of 10%). DOGGR well permitting data for 2013-2017 was used to estimate approximate share of new production. Given substantial uncertainty, this scenario should not be interpreted as a forecast.

balance of production comes from fields that have dominated recent (2013-2017) well completion trends in the state, based on DOGGR data.[49]

If DOGGR were to cease issuance of new permits from 2018, California oil would continue its decline and by 2030, it would avoid the production of about 80 million barrels of oil annually, compared to the EIA's reference scenario.

As described earlier, these reductions in California oil production would lead, via small increases in the global price of oil, to lower global oil consumption, mostly outside California. Still, these cuts to California oil production would presumably not be taken in isolation. Rather, California is also taking aggressive steps to reduce oil *demand*. Taken together, acting on both the demand and supply side could lead to almost no net effect on global oil prices; in other words, there would be no net effect if California supply and demand were both cut by the same amount as a result of the state's climate and energy policy. In this way, supply- and demand-side policies reinforce each other. Either type of policy implemented on its own could result in carbon *leakage*, an outcome in

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Oil derricks pump oil in a field in Bakersfield, California.

which an action to reduce emissions in one region leads to increased emissions in other region. If supply- and demand-side policies are implemented together, this effect is diminished.

In this way, reducing carbon leakage – and the inherent GHG benefit that reduced leakage brings[50] – presents another rationale for limiting California's oil supply. Indeed, the California Air Resources Board requires its climate policies "to minimize emissions leakage to the extent possible."[8] However, the Scoping Plan includes no obvious measures to address leakage associated with reduced oil consumption, and indeed does not estimate the emissions leakage that would occur due to any changes in oil prices. Limiting oil production provides a means to address leakage associated with reduced oil consumption, and could therefore help fill a hole in California's existing emission-reduction policies.

Multiple criteria and policies could be used together

The policy approaches to limiting oil production in California shown in Table 1 are not mutually exclusive. The State could, for example, choose to use multiple criteria for determining where and how to constrain future oil production. Figure 4 below shows one possible way to consider multiple objectives together. In this chart, oil fields could be identified that are some combination of high cost (horizontal axis), high GHG-intensity (vertical axis), large producers (bubble size), and with substantial environmental justice concerns (bubble color). Policymakers could then use such information to sequence a phase-down of oil production. Figure 4 suggests, for example, that the South Belridge field not only combines high life-cycle GHG emissions and a high breakeven oil price, but also extends across an area that is already between the 80th and 90th percentiles in high pollution vulnerability. The State could elect, for instance, to begin a phase-down here. A severance tax or carbon adder could further provide funding to support transitioning businesses and workers to other productive enterprises.

Conclusions

The State of California and Governor Jerry Brown are perceived as global leaders in the effort to limit the dangers caused by climate change. But as the governor himself has noted, "what we are doing is relatively limited [compared] to the existential threat that we face."[52]

As this analysis has shown, phasing out California's oil production is one way to increase the state's ambition. In so doing, it could also perhaps serve as a model policy tool to be considered by the states and nations who come to San Francisco for the September 2018 Climate Summit. Indeed, addressing fossil fuel production is a policy approach that – in addition to its tangible CO_2 reduction benefits – can also capture the public's attention in moving towards a low-carbon economy, and thus encourage greater support for climate action writ large.[53,23]

Phasing down California's oil production can also demonstrate global leadership for the required phase-out of fossil fuels. Equity principles suggest that relatively wealthy regions like California should be the first to start weaning

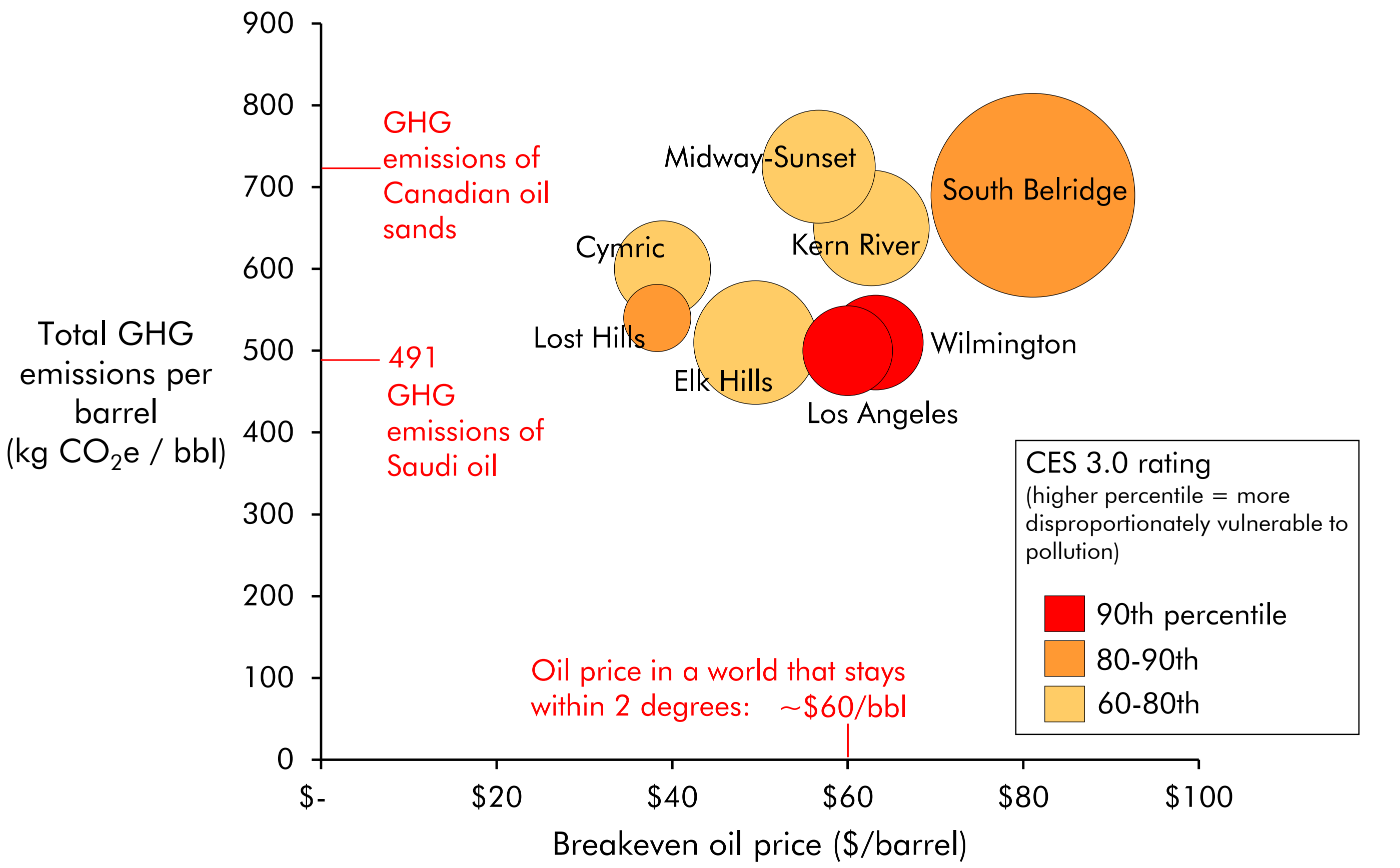

Figure 4: Multiple factors could inform a policy approach to limiting oil production

Source: SEI analysis. Seven largest 2030 oil fields shown, representing 70% of 2030 production (bubble size proportional to production), with costs and quantities as in Figure 2. Colors indicate CalEnviroScreen 3.0 Percentiles of overlying census tracts;[38] Red= 90th percentile of CES 3.0 score and higher; Orange=80th to 90th percentile; yellow-orange = 60th to 80th percentile. GHG-intensity estimates from Oil Climate Index.[51] Low-carbon two degree oil prices as summarized in Erickson and Lazarus (2018).[3]

off fossil fuel extraction, easing the transition for poorer producing regions with fewer resources and options for diversifying their economies.[54,55,56]

Indeed, even the U.S. Department of Interior has considered that a fixed, global carbon budget may mean purposefully limiting U.S. oil production.[30]

And two countries – France and Costa Rica – have announced phase-downs of their oil production. California – and Jerry Brown – could therefore demonstrate to the world that they are also ready to lead by being among the first areas to start phasing down oil supply.

Former President Obama set a precedent for such a policy in his rejection of the Keystone XL pipeline, stating that "we're continuing to lead by example because ultimately if we're going to prevent large parts of this Earth from becoming not only inhospitable but uninhabitable in our lifetimes, we're going to have to keep some fossil fuels in the ground."[57]

Limiting oil production also can help fill a hole in California's existing emission-reduction policies, by addressing carbon leakage that could arise from the state's plans for reducing oil consumption.

Without question, there are political headwinds against such a policy anywhere in the U.S., even in California. But in the long term, the transition away from fossil fuels will need to be managed – actively – in order to be orderly and fair to the workers and communities involved in, and impacted by, oil production. This process will no doubt require approaches beyond those that have been designed or, certainly, legislated to date. Should policy-makers in California seek to further encourage this transition, our analysis shows that there could be several benefits to doing so, and several policy approaches already available.

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An oil platform in state waters off Huntington Beach, California

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1402 Third Avenue, Suite 900
Seattle, WA 98101
USA
Tel: +1 206 547 4000

Author contacts:
Peter Erickson
peter.erickson@sei-international.org
Michael Lazarus
michael.lazarus@sei-international.org

Media contact:
Emily Yehle
emily.yehle@sei-international.org

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Twitter: @SEIresearch, @SEIclimate

Exhibit 12 of 13 - Shamasunder 2018. Community Based Health and Exposure Study

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Article

Community-Based Health and Exposure Study around Urban Oil Developments in South Los Angeles

Bhavna Shamasunder [1,*], Ashley Collier-Oxandale [2], Jessica Blickley [3], James Sadd [4], Marissa Chan [1], Sandy Navarro [5], Michael Hannigan [6] and Nicole J. Wong [7]

1 Urban and Environmental Policy Department, Occidental College, Los Angeles, CA 90041-3314, USA; marissawchan@gmail.com
2 Department of Environmental Engineering, University of Colorado Boulder, Boulder, CO 80309-0427, USA; Ashley.Collier@Colorado.edu
3 Center for Digital Liberal Arts, Occidental College, Los Angeles, CA 90041-3314, USA; blickley@oxy.edu
4 Geology Department, Occidental College, Los Angeles, CA 90041-3314, USA; jsadd@oxy.edu
5 Esperanza Community Housing, Los Angeles, CA 90007, USA; snavarro213@gmail.com
6 Department of Mechanical Engineering, University of Colorado Boulder, Boulder, CO 80309-0427, USA; hannigan@colorado.edu
7 Redeemer Community Partnership, Los Angeles, CA 90018, USA; niki@redeemercp.org
* Correspondence: bhavna@oxy.edu; Tel.: +1-323-341-4695

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Abstract: Oilfield-adjacent communities often report symptoms such as headaches and/or asthma. Yet, little data exists on health experiences and exposures in urban environments with oil and gas development. In partnership with *Promotoras de Salud* (community health workers), we gathered household surveys nearby two oil production sites in Los Angeles. We tested the capacity of low-cost sensors for localized exposure estimates. Bilingual surveys of 205 randomly sampled residences were collected within two 1500 ft. buffer areas (West Adams and University Park) surrounding oil development sites. We used a one-sample proportion test, comparing overall rates from the California Health Interview Survey (CHIS) of Service Planning Area 6 (SPA6) and Los Angeles County for variables of interest such as asthma. Field calibrated low-cost sensors recorded methane emissions. Physician diagnosed asthma rates were reported to be higher within both buffers than in SPA6 or LA County. Asthma prevalence in West Adams but not University Park was significantly higher than in Los Angeles County. Respondents with diagnosed asthma reported rates of emergency room visits in the previous 12 months similar to SPA6. 45% of respondents were unaware of oil development; 63% of residents would not know how to contact local regulatory authorities. Residents often seek information about their health and site-related activities. Low-cost sensors may be useful in highlighting differences between sites or recording larger emission events and can provide localized data alongside resident-reported symptoms. Regulatory officials should help clarify information to the community on methods for reporting health symptoms. Our community-based participatory research (CBPR) partnership supports efforts to answer community questions as residents seek a safety buffer between sensitive land uses and active oil development.

Keywords: oil and gas development; urban oil drilling; cumulative impacts; environmental justice; community-based participatory research; health survey; low-cost sensors; methane

1. Introduction

The consequences for public health of oil development in densely populated urban environments is an understudied research question, but one of great concern to residents surrounding oil and gas development facilities in Los Angeles. Oil and natural gas extraction activity, both using traditional primary production methods as well as secondary methods such as flooding, steam injection, hydraulic fracturing, and acidization, has prompted concerns over impacts to water, air, land, and public health across the United States [1]. Yet, there is little environmental or public health data on the consequences of oil development in urban core cities, such as Los Angeles, with substantial production located near dense populations. The National Institute of Environmental Health Sciences funded Environmental Health Sciences Core Centers recommended that future research should examine exposure and health outcomes related to oil and natural gas development with community engagement as central to study design [2]. Community-based participatory research (CBPR) can be a vital component of research that is designed around the 3Rs—rigor, reach, and relevance—that is critical to the usefulness of scientific findings [3]. Our study is a contribution to CBPR research in an urban oil development context. We examined oil development in South Los Angeles through self-reported community health. We also gathered qualitative information about community knowledge of and experiences living nearby an oil development site. Finally, we tested a low-cost method for identifying methane emissions from oil development in a neighborhood impacted by multiple pollution sources to better discern oil-related exposures.

Research studies on the health impacts of proximity to oil and gas development suggest an important spatial dimension, with those living closer to active wells experiencing greater adverse impacts. Residents living within 0.8 km from a gas well, compared with residents living further away from such active gas development, experience greater impacts on their health from exposure to gas emissions [4]. Greater density and proximity of natural gas wells to maternal residence (within a 10 m radius) were associated with adverse birth outcomes [5]. Residential proximity has also been associated with dermal and respiratory conditions in residents near natural gas extraction activities with distances typically measured at less than a kilometer to two kilometers from well to residence [6].

Los Angeles is an oil-rich basin concentrated across 70 active oil fields [7]. In some neighborhoods, residences are located just 3 ft. away from the boundary of an active drilling and/or production site, with the wellheads as close as 60 ft. from the residence. In Los Angeles County, a population of 10 million people resides amidst more than 5000 active oil and gas wells, with the City of Los Angeles hosting approximately 850 active wells and 4750 wells in the county, adjacent to over 4 million and 10 million residents, respectively. In neighborhoods such as South Los Angeles, wells are located nearby a dense residential population and sensitive land uses such as childcare centers, schools, urban parks and playgrounds, and senior residential and healthcare facilities, many composed of vulnerable populations [8,9]. The proximity of oil wells and production facilities to a dense population makes Los Angeles a critical site for examining the public health consequences and potential exposures from oil and gas development in an urban context. Our community-based health and exposure study is a collaboration between Occidental College, University of Colorado, Boulder, and member organizations of STAND-LA (Stand Together against Neighborhood Drilling-Los Angeles). STAND-LA is a coalition of environmental justice and community groups organized to confront the public health consequences of oil development for residents living amidst active oil development in the City of Los Angeles. Despite the more than 100-year history of oil development in Los Angeles [10], there is a dearth of data on environmental and public health consequences of these long-lived and continuous operations. We sought to generate baseline community data by conducting a preliminary survey through the collection of comparable self-reported health data as well as baseline information about resident experiences of living near active oil development. Further, communities have no access to exposure monitoring data, and air monitoring can be prohibitively expensive [11]. Low-cost sensors are a potential option for generating localized community-relevant monitoring data that can be examined alongside self-reported data.

Los Angeles is a well-documented "riskscape" of environmental hazards and elevated health risk, disproportionately concentrated in poor communities and communities of color [12,13].

CalEnviroscreen, a pollution exposure and health vulnerability screening tool developed by the California Environmental Protection Agency Office of Environmental Health Hazard Assessment for use by State agencies, helps identify communities most affected by multiple sources of pollution, and where people are especially vulnerable to pollution's effects [14]. CalEnviroscreen calculates scores that reflect cumulative impact and vulnerability for every census tract in the state using environmental, health, and socioeconomic information from state and federal government regulatory agencies (Cushing et al. 2015). Vulnerability incorporates individual and community level characteristics that make people more sensitive to pollution's effects, such as young children and people with asthma, and socioeconomic factors, such as poverty, race/ethnicity, and education. The tool ranks communities based on their scores, and then maps these scores, allowing for objective cross-community comparisons. Because the determinants of vulnerability include socioeconomic factors, such as race/ethnicity and income, our CBPR study examines active oil production in two communities with a residential population that is poorer, and with a higher proportion of non-Anglo people than the city or county overall. The West Adams and University Park neighborhoods, surrounding the Jefferson (The Jefferson Drill Site) and AllenCo (the AllenCo Drill Site) oil production sites, are both located in an area identified by CalEnviroscreen as an "environmental justice" community, defined as among the top 25% of most environmentally most environmentally burdened census tracts in the state [15].

Environmental justice (EJ) community organizations have historically recognized and documented health and environmental consequences from polluting industries and other incompatible land uses located near their homes, schools, and playgrounds [16,17]. EJ communities often more actively seek information and gather data related to community hazards to demonstrate the hazards and risks they face, and to better inform policy and decision-making [18]. Residents in Los Angeles neighborhoods near oil development sites report health symptoms such as nosebleeds and headaches, ailments that have also been described with oil and gas production in other areas [19]. Oil production and drilling is associated with exposure to hazardous air pollutants (HAPs) and toxicants, such as BTEX chemicals (benzene, toluene, ethylbenzene, and xylene) [20].

Secondary drilling and production enhancement practices inject fluids into oil and gas reservoir rocks to enhance the recovery of the hydrocarbon products. For example, acidizing is used in Los Angeles, where large volumes and high concentrations of hydrochloric acid, hydrofluoric acid, or other chemicals are injected underground, mixing and reacting with other well fluids, most of which lack adequate hazard evaluation. Oil development facilities within the South Coast Basin submit chemical use reports for certain well activities. The reports indicate chemical ingredients with known air toxics such as hydrogen chloride, xylene, hydrofluoric acid, and ethylbenzene used as part of standard well development and maintenance acidizing practices [21,22].

Residents living near active oil wells and production facilities in Los Angeles often note symptoms such as nosebleeds, headaches, and worsened asthma. In the most highly publicized case, residents of the University Park neighborhood in 2013 complained of foul emissions and reported nosebleeds, headaches, and respiratory problems. These complaints coincided with increased oil production in the nearby field, where production rose 400% in one year following the purchase of the facility by AllenCo Energy Inc. (Los Angeles, CA, USA) (4178 barrels in 2009 to 21,239 barrels in 2010 [23]. Subsequently, the EPA fined AllenCo. The facility is temporarily closed with plans to reopen once it installs emissions control equipment. Other extraction facilities and wells in this and many other densely populated Los Angeles neighborhoods continue to operate.

As proximity to oil and gas development has emerged as important to understanding its public health impacts, policy measures suggest the need for setbacks or buffers as a public health protection [24,25]. Los Angeles requires no buffers or setbacks from oil development operations, which permits very close distances between residents and extraction sites. Responding to community complaints, in April 2017, Los Angeles City Council introduced a motion for the city to study the possibility of a safety buffer [26]. 70% of active wells in Los Angeles are located within a 1500 ft. distance from "sensitive land uses" [27], such as a home, school, childcare facility, urban park or playground, or senior residential facility, as defined by Cal EPA (Table 1). Setbacks have been enacted in municipalities in Colorado, Pennsylvania, and Texas to separate oil and gas development from residences for health and safety protections. Here, we report on the analysis of a random sample household survey of residents living within a 1500 ft. radius of oil development sites. We compare resident self-reported health within the 1500 ft. radius of the site to resident health in Service Planning Area 6 (SPA6), the Los Angeles County Department of Public Health designated area in which South Los Angeles is located and to Los Angeles County residents overall.

In partnership with residents, we also piloted the use of an open-source low-cost air quality monitoring system during the survey period in West Adams (Jefferson Oil Field) as a pilot site. While these sensors present challenges in terms of cross-sensitives and lower accuracy/precision compared with conventional monitoring equipment [28], they have led to more accessible tools that can complement existing monitoring methods and serve as a screening method for concerned communities. In recent years, much work has gone into understanding the capabilities of low-cost sensors [29–31] and they have been utilized in a variety of applications from personal exposure monitoring [32] to high-density networks designed for monitoring in complex urban environments [33]. Sensors have even been calibrated for the detection of ambient levels of methane [34]. We present preliminary results from the calibration and deployment of these same sensors in areas with and without oil and gas activity and discuss how this type of data may further support CBPR efforts. In addition to providing CBPR with new options for data collection, low-cost sensors allow researchers and communities to examine high time-resolution data alongside community-member knowledge, which offers yet another way to engage community expertise to better understand the potential impact of local emission sources, such as oil and gas operations. Through this mixed methods approach, we report on how research engages community expertise as central to the research process and extends knowledge on local health impacts from oil development. We also suggest how community residents living nearby urban oil drilling facilities can contribute to locally relevant health interventions and lend their knowledge to support the development of relevant policy measures.

Table 1. Sensitive land uses in selected areas hosting oil production facilities.

Location	Number of Schools	Childcare Facilities	Schools per 10,000 People	Childcare per 10,000 People	Childcare per sq. Mile
L.A. County	3036	3903	3.09	3.98	1.6
L.A. City	1087	1385	2.88	3.67	2.9
Within 1500 ft. of an active L.A. City Well	40	29	3.25	2.35	1.5
University Park: AllenCo	5	2	7.83	3.13	8.0
Historic West Adams: Jefferson	1	2	1.29	2.59	8.0
Historic West Adams: Murphy	3	1	5.44	1.81	4.0
Wilmington: Warren E&P	0	1	0.00	2.35	2.4
Baldwin Hills: Inglewood Oil Field	2	7	3.64	2.35	4.4

2. Methods

2.1. Neighborhood Profile

The West Adams and University Park neighborhoods in South Los Angeles host well established well fields with sustained and active oil development. CalEnviroscreen identifies these neighborhoods as having significant residential vulnerability when compared to all census tracts Statewide. Esperanza Community Housing and Redeemer Community Partnership are member organizations of STAND LA and the two organizations that took the community lead on this study as the sites are in their service provision area. Esperanza is a longstanding community organization in the University Park area, where the AllenCo oil site is located. The neighborhood is predominantly Latino (76%) with 72% of residents living 200% below the poverty line and 81% renters. Redeemer Community Partnership is a community development corporation in the West Adams neighborhood for over 25 years and has been organizing the community around the Jefferson Drill Site. The neighborhood is 87% residents of color, with 58% Latino and 20% African-American. 20% of the population is under the age of 5 (as compared to 7% for Los Angeles County), 68% of residents live 200% below the poverty line, and 69% of residents are renters (Table 2).

Table 2. Demographics of West Adams and University Park within the 1500 ft. buffer.

Population	West Adams Buffer Area 1500 ft. around Jefferson Oil Field	University Park Buffer Area, 1500 ft. around AllenCo Oil Field	City of Los Angeles
Total Population	6641	5401	2,546,606
% Age 5 or under	20.90%	5.31%	7.63%
% Age 65 or older	9.92%	6.94%	6.95%
% People of Color	87.82%	84.17%	72.85%
% Non-Hispanic Black	20.86%	8.17%	9.99%
% Non-Hispanic White	12.18%	15.83%	27.15%
% Hispanic	58.20%	76.00%	50.85%
% Linguistically Isolated	23.42%	39.21%	12.37%
% Less Than High School	42.49%	46.72%	18.91%
Per Capita Income	$11,194	$11,203	$18,839
Median Household Income	$23,912	$20,115	$37,723
Poverty (LT 150%)	51.51%	59.39%	20.57%
Poverty (LT 200%)	64.88%	72.30%	27.57%
% Renters	68.77%	81.13%	34.70%
Median Household Size	2.7	3.4	1.7

2.2. Study Area and Sample Selection

The study areas were defined to represent the neighborhoods surrounding the wells and production facilities at two locations that produce oil from the Las Cienegas oilfield (Figure 1). Study areas were defined by constructing a circular buffer using ArcGIS (Esri, Redlands, CA, USA), with a 1500 ft. radius surrounding the outer perimeter of the two oil production sites (Figure 1). The Jefferson Drill Site (Jefferson) is located in the West Adams neighborhood, and the AllenCo Drill Site (AllenCo) is located in the University Park neighborhood of Los Angeles. We chose a 1500 ft. buffer based on distances considered by other urban cities, such as Dallas [35]. It should be noted that Site C was utilized only for the air monitoring portion of the study; its description appears subsequently.

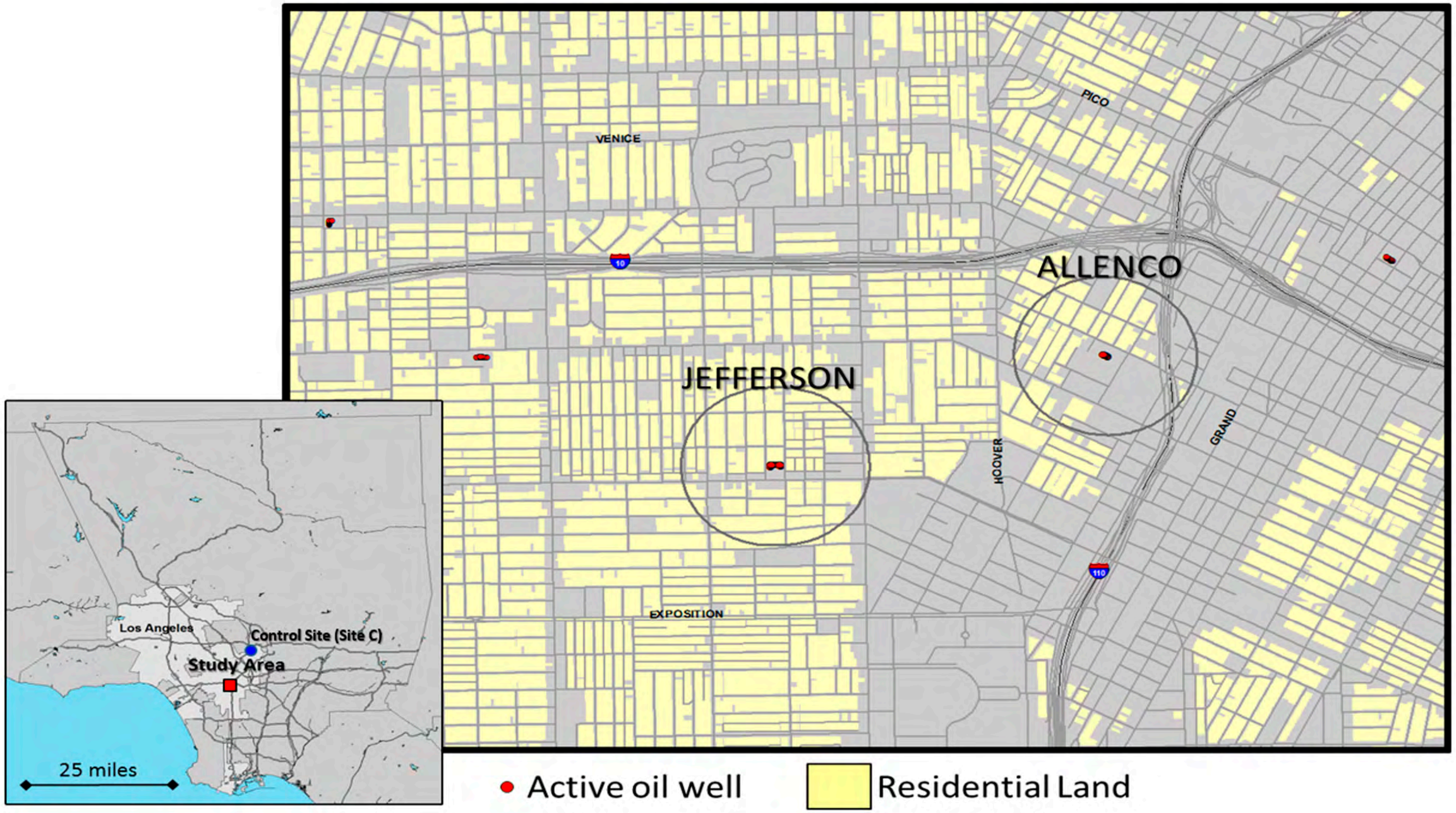

Figure 1. Location map. Study area is located in the mid-city area of Los Angeles, just west of downtown. Circles are 1500 ft. radius buffers surrounding active wells. Note active oil wells in other nearby residential neighborhoods.

These buffers were then used to capture census polygons, sensitive land uses, land use information, and residential street addresses used in the study. From the residences inside each buffer, a random sample of street addresses was selected from tax parcel records obtained from the LA County Office of the Assessor, for the purposes of administering the survey. To determine the minimum number of households to survey at each study site, we calculated the sample size required from each population to estimate the value of a continuous variable with a 95% CI and a 10% margin of error. The number of random sample addresses was determined using an estimate of the variability in responses expected at a 95% CI. We also performed a one-sample proportion test for physician-diagnosed asthma (age 0–17) and emergency room visits by asthmatics to determine the minimum proportions in our surveyed population that we could detect as being significantly different from the overall rates measured for LA County by CHIS and the LA County Health Department for a range of possible sample sizes. Based on this analysis, we selected a target minimum sample size of 76 households around AllenCo and 84 households around Jefferson, conducting the surveys at the addresses identified using a random sampling algorithm to ensure systematic sample coverage (Human Subjects Code: Sham-F16006).

2.3. Survey Instrument

We designed a survey instrument in collaboration with Esperanza Community Housing and Redeemer Community Partnership to identify baseline informational questions that were of community importance, such as ratings of the environmental quality of their neighborhood, feelings of safety living in the neighborhood, and resident knowledge of the site. For the health portion of the survey, community residents were primarily interested in respiratory health and reproductive health, in particular asthma and birth outcomes. We drew from questions asked in the California Health Interview Survey (CHIS) for which the questionnaires are publicly available, in order to compare our study area to the CHIS survey data. CHIS is a random-dial telephone survey that is conducted on a continuous basis allowing the survey to generate timely one-year estimates. The survey provides representative data on all California counties and over samples and creates small-area estimates in Los Angeles County. Surveys were created in Qualtrics, and paper copies were generated for field use.

2.4. CBPR Method for Administration of Resident Surveys: Data Collection and Community Building

Health surveys are a well-recognized method of community organizing in an environmental justice context [36]. The survey provided a vehicle for community organizing and education about issues of concern in the neighborhood. Residents were able to provide their information if they wanted to be contacted for report back on the survey or other community events. In partnership with Esperanza's trained network of community health workers, *Promotoras de Salud* in Action, we conducted the door-to-door surveys of residents in Spanish and English. *Promotora de Salud* networks are recognized within CBPR environmental justice research [37]. *Promotoras de Salud* live and work in the community, are engaged long-term in community building, and have a baseline of trust in the neighborhood. They are agile at accessing residents, many of whom work in service sector jobs, the night shift, or have other non-traditional working hours. We also trained four bilingual Occidental College students to conduct surveys alongside *promotoras*. Using the addresses generated from the random household sample, we visited each household on our list starting in March 2016 and continued through May 2016. If we could not find anyone at home, we returned on different days and at different times until the survey could be completed. In addition to our random household sample, residents became interested in the survey as they saw surveyors in conversation with other residents. These residents were included in a snowball sample collected to supplement the randomly designed surveys if the address fell within the 1500 ft. buffer. Through these methods, we were able to achieve a high survey response rate.

In addition to asthma and respiratory health, we asked questions about infertility and birth outcomes because community organizers were interested in these variables. We provided this self-reported information back to the community but we do not include an analysis of these data here as we did not have specific enough data to do a birth outcomes analysis, and had informed residents in advance. Thus, that information serves to inform internal community efforts moving forward and should be considered for future research.

2.5. Survey Analysis

Surveys were coded to correspond with a created codebook and entered by hand into Qualtrics. All subsequent analyses were performed in the statistical software package R (version 3.3.0; R Development Core Team, 2016). We calculated proportions for demographic variables and health conditions of interest, excluding respondents/households that did not answer the corresponding question.

2.5.1. Health Insurance

We collected data on the type of health insurance for all members of surveyed households. To determine the proportion of people in surveyed households that were uninsured, we subtracted the total number of people with each type of health insurance from the total number of residents of households surveyed. Individuals that responded "unknown" for health insurance type were excluded from the analysis.

2.5.2. Asthma and Asthmatic Hospitalization Rate

To account for age-dependent differences in asthma diagnoses, we calculated an age-adjusted asthma rate. We determined the rates of diagnosed asthma for survey respondents in two age categories (18–64 years and 65+ years) and for children (0–17 years) residing in surveyed households. Households with smokers were excluded from the analysis. To estimate the age-adjusted asthma rate, the asthma rate for each age category (0–17, 18–64 and 65+) was weighted using the age distribution for Los Angeles County. The asthma hospitalization rate was calculated only for respondents that had previously been diagnosed with asthma.

We compared self-reported demographic and health outcomes from this survey to publicly available data for both Service Planning Area 6 (SPA6) and Los Angeles County from the California Health Interview Survey (CHIS) and the American Community Survey 5-year rollup 2009–2013 [38]. To determine if self-reported proportions differed from previously published proportions for Los Angeles County and SPA6, we performed one-proportion z-tests.

2.6. Air Quality Monitoring with Low Cost Sensors

Low-cost sensor systems are typically small and low power, which makes them fairly easy to deploy at potential sites within the community (e.g., homes, schools, or businesses). This flexibility allows researchers and community members to work together in choosing sites that will best inform the research question. In this pilot study, the monitors were set-up and maintained by community-based research partners at three field sites. These sites include three residences—one near an active drill site (West Adams, labeled Site A), one across the street from an inactive drill site (AllenCo, labeled Site B), and one in an area with no drilling (our control site, labeled Site C). Sites A and B were located in the Study Area (Figure 1), whereas Site C was located roughly seven miles away in Northeast Los Angeles. Site C was intended to serve as a comparison for the low-cost sensor data portion of the study, and no other measures were taken at this location. All sites were relatively similar in terms of land use and proximity to other major pollution sources (e.g., highways). The sites were selected to provide a preliminary example of what sensors can tell us regarding the differences in methane levels/trends in areas with drilling versus those without drilling. Issues with the data logging system at Site B resulted in data loss, and this incomplete data was not included in the analysis of the field deployment data—meaning the figures below illustrate the comparison between the West Adams site and the control site. The system used for data logging and acquisition is an open-source design termed a U-pod [39]. This system supports several air quality and environmental sensors including the Figaro TGS 2600 metal oxide-semiconductor VOC sensor and the RHT03 temperature and relative humidity sensor. Field calibration for methane was used to convert raw sensor signal data to volumetric concentrations; this method involves co-locating the low-cost sensors with a high-quality, calibrated reference instrument and then using regression analysis to develop a predictive model [40]. In this case, the U-pods were co-located together with a Baseline-Mocon Series 9000 NMHC Analyzer before and after the field deployment, and data from the monitor with the most complete set of calibration data were used to generate the predictive model that was applied to the normalized data from the remaining monitors. Data used for calibration and field data analysis were minute-averaged. It should be noted that these results are preliminary and intended to explore the potential for this technology in the context of CBPR; more rigorous calibration and validation of these sensors is explored in a separate paper [41].

3. Results

3.1. Demographics

We surveyed 84 households comprising 315 residents in University Park and 119 households comprising 498 residents in West Adams. In both sites, more than 50% of surveyed households had incomes of $20,000 or less (University Park: 57.1%, West Adams: 53.7%). Median household income according to census data (2010–2015 ACS 5-year rollup) for West Adams is $25,980, and for University Park is $20,115. For both sites, the proportions of households with self-reported incomes of less than $20,000 were significantly higher than for Los Angeles County (LA County: 17.2%; University Park: 57.1% [95% CI: 48.3–65.9%], $n = 70$, $z = 8.85$, $p < 0.001$; West Adams: 53.6% [95% CI: 45.5–61.8%], $n = 82$, $z = 8.75$, $p < 0.001$) and SPA6 (SPA6: 30.1%; University Park: 57.1% [95% CI: 46.4–67.9%], $n = 70$, $z = 4.93$, $p < 0.001$, West Adams: 53.6% [95% CI: 43.7–63.6%], $n = 82$, $z = 4.65$, $p < 0.001$). For both sites, the reported proportions of residents on Medi-Cal were significantly higher than the previously reported rate for Los Angeles County (LA County: 30.1%; University Park: 46.0% [95% CI: 40.9–51.1%], $n = 315$, $z = 6.21$, $p < 0.001$; West Adams: 44.8% [95% CI: 40.8–48.9%], $n = 484$, $z = 6.21$, $p < 0.001$) but not the reported rate for SPA6 (SPA6: 50.1%; University Park: 46.0% [95% CI: 40.5–51.6%], $n = 315$, $z = -1.44$, $p = 0.925$, West Adams: 44.8% [95% CI: 40.4–49.3%], $n = 484$, $z = -2.31$, $p = 0.989$). In University Park, the proportion of uninsured residents was significantly higher than the previously reported rate of 10.4% for Los Angeles County (16.2% [95% CI: 12.6–19.7%], $n = 315$, $z = 2.29$, $p = 0.01$) and 12.0% for SPA6 (16.2% [95% CI: 12.6–19.8%], $n = 315$, $z = 2.29$, $p = 0.01$). In West Adams, the proportion of uninsured residents was not significantly different from Los Angeles County (11.0% [95% CI: 8.2–13.7%], $n = 484$, $z = 0.40$, $p = 0.35$) or SPA6 (11.0% [95% CI: 8.1–13.8%], $n = 484$, $z = -0.71$, $p = 0.76$) rates [42].

3.2. Community Knowledge and Experiences

Many respondents (University Park: 45.8%, West Adams: 38.9%) reported that they did not have prior knowledge of the oil production site. Those that knew of the facility (University Park: 33%, West Adams: 42.4%) had questions about the site. Most respondents (University Park: 78.5%, West Adams: 76.9%) answered they "definitely did not" or "probably did not" know how to make a report to the South Coast Air Quality Management District or other agency. Some respondents (University Park: 15.7%, West Adams: 27.5%) reported that odors from the site had prevented daily activities. Very few of the respondents had previously reported odors to the gas company (University Park: 2.4%, West Adams: 3.6%), the Los Angeles Department of Public Health (University Park: 2.4%, West Adams: 1.8%), the South Coast Air Quality Management District (University Park: 2.4%, West Adams: 2.7%), or any other entity (University Park: 3.7%, West Adams: 1.8%).

3.3. Reported Health Symptoms

For both University Park and West Adams survey sites, the age-adjusted rate of diagnosed asthma was significantly higher than in SPA6 (SPA6: 9.8%; University Park: 16.1% [95% CI: 8.6–23.6%], z = 3.41, $p < 0.001$; West Adams: 20.3% [95% CI: 13.5–27%], z = 3.02, $p = 0.001$). Asthma prevalence in West Adams but not University Park was significantly higher than that in Los Angeles County (LA County: 13.0%; University Park: z = 0.82, $p = 0.21$; West Adams: z = 2.10, $p = 0.02$) [43]. Moreover, 15.5% [95% CI: 8.5–22.5%] of all respondents in West Adams and 12.1% [95% CI: 4.7–19.6%] of all respondents in University Park reported experiencing asthma symptoms (coughing and wheezing) on a weekly or daily basis. Respondents with diagnosed asthma reported rates of ER visits in the previous 12 months that were not significantly higher than SPA6 (SPA6: 26.8%; University Park: 18.8% [95% CI: −3.0–40.5%], $n = 16$, z = −0.73, $p = 0.766$; West Adams (25.0% [95% CI: 8.59–41.4%], $n = 28$, z = −0.21, $p = 0.585$) or Los Angeles County (LA County: 17.0%; University Park: 18.8% [95% CI: −3.0–40.5%], $n = 16$, z = 0.19, $p = 0.426$; West Adams: (25.0% [95% CI: 8.59–41.4%], $n = 28$, z = 1.13, $p = 0.129$) [44].

3.4. Low-Cost Sensor Calibration and Field Data

Comparing the calibrated sensor data and the methane reference data reveals an R-squared of 0.45 and a root mean squared error (RMSE) of 0.14 ppm. While the R-squared seems low, given the RMSE and the range of methane values observed during calibration, the signal-to-noise ratio is approximately 4.79, indicating that enhancements in methane above our error are likely visible. Additionally, researchers in a study in rural Alaska noted that, despite low R-squared values when comparing calibrated sensor data to validation data, the methane's diurnal patterns were clearly resolved, meaning the sensor data still included valuable information [34]. When we compare the low-cost sensors' performance, there is an average correlation coefficient of 0.90 for each sensor pairs' calibrated data, which demonstrates that the sensors are well correlated with each other when co-located and the calibration model is performing consistently.

The correlation coefficient for the sensors at Sites A and C decreases to 0.35 for the field data indicating differences between these two sites that are visible in the sensor data. Figure 2 compares the complete calibrated field data from Sites A and C. While the median is slightly higher at Site C, most of the data from both sites is varying within a similar range as is demonstrated by similarity in difference between the 95th and 5th percentiles for Sites A and C (0.548 and 0.551 ppm, respectively). However, an important difference between the two sites is the presence of short-term increases in methane occurring at one site and not the other, which are larger and more frequent at Site A (nearly 1 ppm larger). Figure 3b–d illustrate some of these increases, confirming that, overall, the diurnal trends and methane ranges at each site are similar and that these short-term events may be driving the difference in correlation.

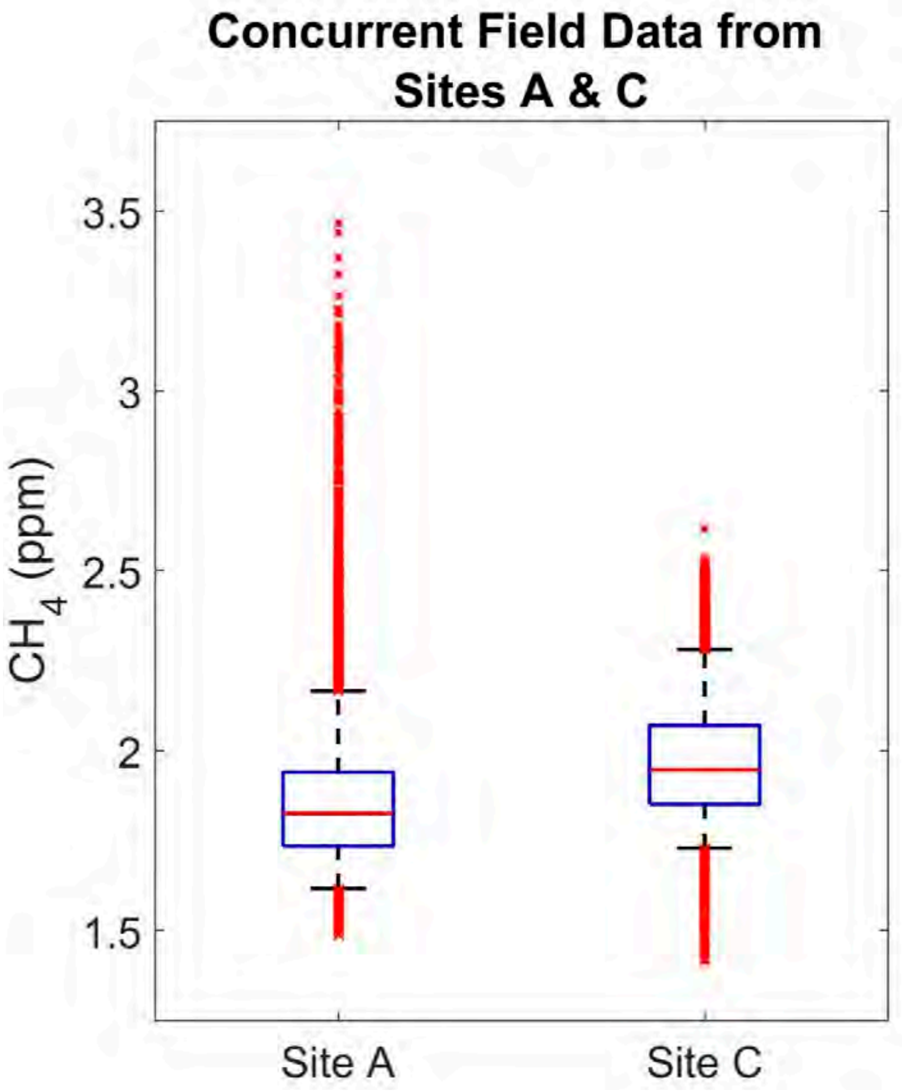

Figure 2. Concurrent field data from Sites A and C.

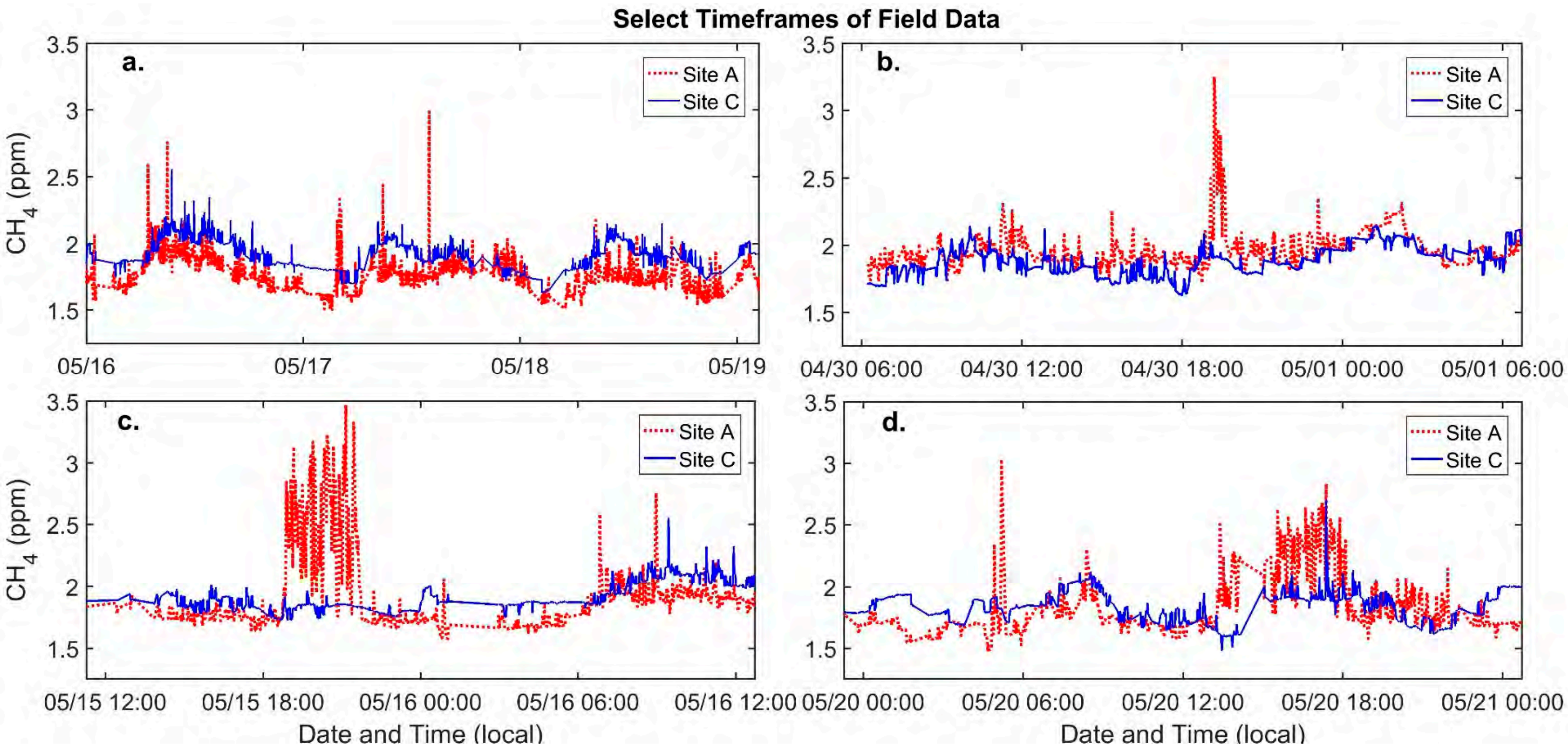

Figure 3. Select timeframes of field data that illustrate relatively large differences in methane between Sites A and C. (**a**) a period of four days including several examples of enhanced methane; (**b**) a 24-h period including an approximately 1 ppm increase in methane; (**c**) a 24-h period depicting an approximately three-hour long methane enhancement; (**d**) a 24-h period including several enhancements in methane.

4. Discussion

Our random household sample and exposure monitoring within 1500 ft. of oil development sites is the first study in partnership with residents living in very close proximity to oil development in Los Angeles. It is also the first study, to our knowledge, to compare the self-reported health of residents within 1500 ft. of oil development to residents in the broader area of South Los Angeles (SPA6) and Los Angeles County. The testing of low-cost sensors supports community organization efforts to collect air monitoring data as related to oil development in their neighborhoods. There are currently no buffers or setbacks between sensitive land uses, such as homes and schools, and oil development in Los Angeles. West Adams and University Park are located within an area identified by the State of California as having high vulnerability to the health impacts of pollution due to the SES status of residents exposed to multiple sources of pollution. More than 50% of residents reported household incomes of $20,000 or less as compared to 29% of households in SPA6 and 17% in LA County. The median household income is lower in both communities than in the City (Table 2). Within the West Adams buffer, 20% of residents identify as Non-Hispanic Black as compared to 10% in the City. 76% of residents within the University Park buffer and 58% in West Adams buffer identify as Hispanic as compared to 50% in the City.

We gathered community experiences living adjacent to oil development sites. Many residents (University Park: 45.8%, West Adams: 38.9%) living within 1500 ft. did not know that an oil development site was located in the neighborhood. This may be due to tall walls and landscaping surrounding both sites, and to visible private property and no trespassing signage. From our survey, one of the main burdens appeared to be odors, which some respondents reported prevented daily activities (University Park: 15.7%, West Adams: 27.5%). However, only a few respondents said they had reported odors or any health symptoms to the gas company, the Los Angeles Department of Public Health, the South Coast Air Quality Management District, or any other entity, as most responded that they lacked information as to how to report. Further, since most residents are unaware of these activities, they may attribute symptoms to allergies or general poor air quality.

Oil and gas development is associated with degraded air quality and exposure to air pollution [45,46] as well as exacerbated respiratory conditions and asthma [47]. For both University Park and West Adams, compared with SPA6, resident-reported asthma prevalence was significantly higher. Respondents in West Adams (15.5%) and University Park (12.1%) reported experiencing asthma symptoms of coughing and wheezing on a weekly or daily basis. Decreases in ambient pollution levels in Southern California have been associated with statistically significant decreases in asthma-related symptoms in children [48]. Children under the age of 5 living within the West Adams buffer area represent 20% of the population as compared to 7% of residents in the city of Los Angeles, and this group is more biologically sensitive to air pollution health impacts. Future studies might consider children's health specifically. Respondents with diagnosed asthma in our sample did not report higher rates of emergency room visits in the previous 12 months (West Adams 25%; University Park 19%) than previously reported in SPA6 or LA County, but our sample size was small (16 diagnosed asthmatics for UP (University Park) and 28 diagnosed asthmatics for WA (West Adams)).

The reliance on self-reported information is a possible limitation of the study. Surveys are not an optimal method for estimates for some kinds of health outcomes of interest, such as birth defects, especially in a population that may be transient. However, the use of questions from a validated survey facilitated comparison for asthma and respiratory health. While both Jefferson and AllenCo have long operated in these neighborhoods, AllenCo was closed at the time of the survey to address their lack of emissions controls. We report both University Park and West Adams rates here given the significant community interest in both fields and concern over AllenCo's reopening. Another limitation of the survey could be awareness bias. The study questionnaire asked respondents about knowledge of their environment and the oil development, as well as health status. One way to reduce this bias may be to control for the effect of awareness [6]. In our case, community organizations were interested in learning both about environmental awareness and self-reported health.

Air Quality Monitoring

The similarities between the data from Sites A and C seen in the diurnal patterns and the ranges of methane variation are likely explained by regional methane trends and meteorology. There was an offset between the two datasets (seen in the differing medians); however, this offset was less than the RMSE determined during calibration. Spatial differences occurred at a finer temporal scale as can be observed in Figure 3, which depicts periods of elevated methane lasting from approximately 10 min to up to 3 h. These events included differences in methane between the two sites greater than 1.0 ppm, well above the RMSE of the calibration model (0.14). Given that these events occurred at one site and not the other, they were likely the result of an emission source nearer to Site A. This was even more evident for the events that occurred during daytime hours when more, atmospheric mixing is typically taking place [49]. Additional measurements would aid in further narrowing down the source of these events. For example, wind speed and direction information combined with data from multiple sensors might point to the origin of emissions. While data from different types of low-cost sensors could possibly provide more information on the composition of the plumes causing these events. Another benefit of utilizing low-cost sensors in a CBPR context is that local experience, such as observations about local activities or odors, can improve interpretations of the data. On one day depicted in Figure 3, nearby residents reported seeing heavy equipment being used at the active drill site. If similar methane enhancements were observed every time this activity occurred, it would indicate a correlation worthy of further investigation. Examining this qualitative data alongside quantitative data provided by low-cost sensors may result in a more comprehensive understanding of the community's experiences, which could in turn carry through and inform community-based action or potentially policy recommendations.

5. Conclusions

Urban oil development is an under-researched issue. It is difficult to examine oil-development-related impacts in a cumulatively burdened context, but it is critical to do so. Our preliminary community-based survey and low-cost sensor field experiment considers resident health and the rights of residents to have knowledge about their communities and supports hypothesis generation for future air monitoring or health studies. It also points to the need for regulatory agencies to provide community education about reporting experiences such as odors as well as facilitate diverse methods to be able to do so. It leads to questions that require more complex scientific design than possible in this study with limited resources and raises the imperative that communities be involved in the research. Studies on oil and gas development have well associated distance with worsened air pollution, an issue of significant concern in Los Angeles. The Inter-Environmental Health Sciences Core Center Working Group recommends that ambient air quality be measured at active drilling sites and be compared with baseline measurements in adjacent areas without active oil and gas drilling [2]. A low-cost sensor approach to measure methane and total non-methane hydrocarbons could facilitate these types of comparisons, providing preliminary information on potential exposure differences that could inform additional air quality sampling or possibly action by residents or policymakers to lower exposures. This recommendation, in particular, is relevant to Los Angeles oil development and should be considered in future studies. One possible avenue is to employ a daily log model where participants note their symptoms and experiences over a period of time while also collecting local sensor data. These could then be examined side by side. Buffers/setbacks are well recognized as protective by the regulatory authorities such as local air districts and should be incorporated into neighborhood oil development sites to protect community health [50]. This research supports community-based research methods in the context of oil and gas development. CBPR-generated data can support community building as residents seek a setback or buffer between sensitive land uses and oil development citywide.

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Author Contributions: Bhavna Shamasunder designed and supervised the research and analysis and co-wrote the paper. Ashley Collier-Oxandale conceived and designed the air monitoring experiments, analyzed the air monitoring data, and co-wrote the paper. Michael Hannigan supervised analysis of the air monitoring and contributed to the writing. James Sadd conducted the mapping, supported study design, mapped the random household sample, conducted neighborhood level demographic analysis, and contributed to the writing. Jessica Blickley conducted statistical analysis of survey results and contributed to the writing. Marissa Chan was the undergraduate research assistant to Bhavna Shamasunder and James Sadd, created GIS household level maps to support field surveys, supervised undergraduates to enter written surveys into Qualtrics, and created the codebook. Sandy Navarro co-wrote the survey questionnaire, trained *Promotoras de Salud*, supervised the field research, and contributed to the writing. Nicole J. Wong supported field research, survey questionnaire development and contributed to the writing.

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Exhibit 13 of 13 - Tran et al 2020. Residential Proximity to Oil and Gas Birth Outcomes

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Residential Proximity to Oil and Gas Development and Birth Outcomes in California: A Retrospective Cohort Study of 2006–2015 Births

Kathy V. Tran,[1] Joan A. Casey,[1,3] Lara J. Cushing,[3,4] and Rachel Morello-Frosch[1,2]

[1]School of Public Health, Division of Environmental Health Sciences, University of California, Berkeley, California, USA
[2]Department of Environmental Science, Policy and Management University of California, Berkeley, California, USA
[3]Department of Environmental Health Sciences, Columbia University Mailman School of Public Health, New York, New York, USA
[4]Department of Health Education, San Francisco State University, San Francisco, California, USA

Background: Studies suggest associations between oil and gas development (OGD) and adverse birth outcomes, but few epidemiological studies of oil wells or inactive wells exist, and none in California.

Objective: Our study aimed to investigate the relationship between residential proximity to OGD and birth outcomes in California.

Methods: We conducted a retrospective cohort study of 2,918,089 births to mothers living within 10 km of at least one production well between January 1, 2006 and December 31, 2015. We estimated exposure during pregnancy to inactive wells count (no inactive wells, 1 well, 2–5 wells, 6+ wells) and production volume from active wells in barrels of oil equivalent (BOE) (no BOE, 1–100 BOE/day, >100 BOE/day). We used generalized estimating equations to examine associations between overall and trimester-specific OGD exposures and term birth weight (tBW), low birth weight (LBW), preterm birth (PTB), and small for gestational age birth (SGA). We assessed effect modification by urban/rural community type.

Results: Adjusted models showed exposure to active OGD was associated with adverse birth outcomes in rural areas; effect estimates in urban areas were close to null. In rural areas, increasing production volume was associated with stronger adverse effect estimates. High (>100 BOE/day) vs. no production throughout pregnancy was associated with increased odds of LBW [odds ratio (OR) = 1.40, 95% confidence interval (CI): 1.14, 1.71] and SGA (OR = 1.22, 95% CI: 1.02, 1.45), and decreased tBW (mean difference = −36 grams, 95% CI: −54, −17), but not with PTB (OR = 1.03, 95% CI: 0.91, 1.18).

Conclusion: Proximity to higher production OGD in California was associated with adverse birth outcomes among mothers residing in rural areas. Future studies are needed to confirm our findings in other populations and improve exposure assessment measures. https://doi.org/10.1289/EHP5842

Introduction

Oil and gas development (OGD) by the U.S. petroleum industry spans decades in many states but concern about its potential health and equity impacts did not gain traction among researchers until the recent rapid increase in hydraulic fracturing (HF) (Finkel and Law 2011; Kovats et al. 2014; Mitka 2012). As of 2017, California (CA) was one of the top five producers of crude oil in the country (U.S. EIA 2018a, 2018b). Four of the 10 largest U.S. oil fields are in CA's San Joaquin and Los Angeles Basins (Long et al. 2015a), and unlike newer shale gas plays, most of CA's natural gas is extracted from reservoirs also producing oil (Long et al. 2015b). Given the long history of OGD in CA, stimulation techniques, such as water and steam injection and HF, are primarily used at established sites rather than newly drilled wells. Oil recovered via water flooding and steam injection (conventional enhanced oil recovery methods) accounted for 76% of the state's oil production in 2009 (Long et al. 2015b), whereas HF, an unconventional stimulation technique, accounted for 20% of CA's oil production in the last decade. Due to types of geological formations, HF practices in CA differ from other states, potentially resulting in differing environmental hazards (Long et al. 2015b). OGD production in CA also occurs in both rural and urban settings in comparison with other states, such as rural Pennsylvania and Colorado, where many epidemiological studies have been conducted (Casey et al. 2015; Currie et al. 2017; Hill 2018; McKenzie et al. 2014; Rasmussen SG et al. 2016; Tustin et al. 2017). Therefore, an epidemiological study of the relationship between adverse birth outcomes and OGD in CA, a state with a diverse population and the most annual births of any U.S. state, can provide insights about the potential health impacts of OGD exposure in both rural and urban areas.

Characterizing exposures related to OGD poses significant measurement challenges because multiple environmental hazards are associated with different stages of extraction and production. OGD involves the development of oil and gas sites and wells (production and injection for enhanced recovery), transport of materials to and from well sites, drilling, operation of equipment to recover oil and gas, and collection and disposal of chemicals and waste separated from the raw oil and gas (Long et al. 2015a). These activities are associated with diverse environmental hazards, including air and water pollutants, noise, odors, excessive and inappropriate lighting, and undesired land use changes (Adgate et al. 2014; Long et al. 2015a). The application of unconventional techniques presumably enhances the environmental burdens because the additional toxic chemicals that are used can potentially be released into air, water, and soil (Adgate et al. 2014; Long et al. 2015a; Macey et al. 2014; Roy et al. 2014; Vengosh et al. 2014).

Air pollutants associated with OGD include particulate matter (PM) with an aerodynamic diameter of <2.5 μm ($PM_{2.5}$), diesel PM, nitrogen oxides (NO_x), secondary ozone formation, mercury, and volatile organic compounds (VOCs) like benzene, toluene, ethylbenzene and xylene (BTEX) from truck traffic, drilling, hydraulic fracturing, production, and flaring (Allshouse et al. 2019; Brantley et al. 2015; Colborn et al. 2014; Eapi et al. 2014; Esswein et al. 2014; Franklin et al. 2019; Goetz et al. 2015; Koss et al. 2017; Lan et al. 2015; Macey et al. 2014; Marrero et al. 2016; Maskrey et al. 2016; Mellqvist et al. 2017; Roy et al. 2014; Warneke et al. 2014). Additionally, fugitive toxic air contaminants can escape at the wellhead (Garcia-Gonzales et al. 2019; Warneke et al. 2014) that might affect health near the points of release. Water contaminants

Address correspondence to R. Morello-Frosch, Department of Environmental Science, Policy and Management, University of California, Berkeley, 130 Mulford Hall, Berkeley, CA 94720-3114. Telephone: (510)643-6358. Email: rmf@berkeley.edu or K. Tran. Email: kvtran@berkeley.edu

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associated with OGD include gas-phase hydrocarbons, chemicals mixed in drilling fluids, and naturally occurring salts, metals, and radioactive elements within shale that surface with wastewater along with recovered oil and gas and that can contaminate potable water via leaks and spills or evaporate (Adgate et al. 2014; Hildenbrand et al. 2015; Long et al. 2015a; Vengosh et al. 2014). Noise pollution is associated with well pad construction, truck traffic, drilling, pumps, flaring of gases, and other processes (Allshouse et al. 2019; Blair et al. 2018; Ebisu and Bell 2012; U.S. BLM 2006). Drilling and production activities occur both during the daytime and nighttime, and light pollution has been previously reported as a nuisance in communities undergoing unconventional OGD (Long et al. 2015a), suggesting OGD may affect the health of nearby communities via increased psychosocial stress.

Several OGD-related environmental exposures have been linked to reduced birth weight and gestational age: air pollution, e.g., $PM_{2.5}$, NOx, SOx (Basu et al. 2014; Dadvand et al. 2013, 2014; Ebisu and Bell 2012; Long et al. 2015a; Morello-Frosch et al. 2010; Ponce et al. 2005; Ritz et al. 2007); noise pollution (Arroyo et al. 2016; Gehring et al. 2014); some of the chemical compounds found in OGD wastewater (Long et al. 2015a; Valero de Bernabé et al. 2004); and psychosocial distress (Dominguez et al. 2008; Goldenberg et al. 2008; Rondó et al. 2003; Valero de Bernabé et al. 2004). Previous studies examining the relationship between unconventional OGD and birth outcomes provide suggestive evidence of adverse effects. Although study designs vary, most have characterized OGD exposure based on the density and distance of HF shale gas wells near the maternal residence in urban and rural Colorado (McKenzie et al. 2014, 2019), Pennsylvania (Casey et al. 2015; Currie et al. 2017; Hill 2018; Ma 2016; Stacy et al. 2015), Oklahoma (Janitz et al. 2019), and urban Texas (Walker Whitworth et al. 2018, 2017). Among the 10 studies, 8 evaluated our outcomes of interest. Some studies found greater exposure to OGD was associated with reductions in term birth weight (tBW) (Hill 2018; Stacy et al. 2015) and increased odds or incidence of low birth weight (LBW) (Currie et al. 2017; Hill 2018), preterm birth (PTB) (Casey et al. 2015; Walker Whitworth et al. 2018, 2017), and small for gestational age births (SGA) (Hill 2018; Stacy et al. 2015). However, those studies also reported statistically insignificant (Casey et al. 2015; Whitworth et al. 2017) or inverse associations (McKenzie et al. 2014; Stacy et al. 2015) for some birth outcomes.

Building on this research, our study focused on OGD in CA. We conducted our analysis in regions where OGD is concentrated: the Sacramento Valley, San Joaquin Valley, South Central Coast, and South Coast air basins. To our knowledge, our retrospective cohort study with births from 2006–2015 is the first to evaluate prenatal OGD exposure from oil as well as gas wells, inactive as well as active wells, and non-HF and HF wells in rural and urban settings of CA.

Methods

Study Population

Birth records for 1 January 2006 to 31 December 2015 were obtained from the California Department of Public Health (CDPH). CDPH collects statewide birth records that include mother's residential address at the time of birth, which we geocoded to assign exposure to OGD exposure and area-level covariates using ArcGIS (ESRI). Births with missing street-level addresses or that could not be successfully geocoded after a manual cleaning of the address fields for spelling and punctuation errors were excluded (5%). We selected the Sacramento Valley, San Joaquin Valley, South Central Coast, and South Coast air basins because they had the highest well densities in CA between 2005 and 2015 (Figure S1). We illustrate the construction of the study population in Figure 1. Exclusion criteria included missing last menstrual period (LMP) date, which was approximated as the date of conception and used to estimate gestational age (3%); congenital anomalies or abnormal birth conditions such as cleft lip and Down's syndrome (4%); plural births, e.g., twins, triplets (4%); implausible birth weights of less than 500 g or greater than 5,500 g (4%) (Alexander et al. 1996; Padula et al. 2014; Ponce et al. 2005; Talge et al. 2014); and implausible gestational ages of less than 22 or greater than 44 wk (4%) (Alexander et al. 1996; Talge et al. 2014). To limit unmeasured confounding and enhance comparability of exposed and unexposed populations, we also excluded births to mothers who did not live within 10 km of at least one oil/gas production well (3%). Finally, we excluded observations with any missing covariates or outcomes (2%) to arrive at a final study population of 2,918,089 births ($N = 2,718,629$ term births). All study protocols were approved by the Institutional Review Board of the CA Department of Public Health (#13-05-z) and the University of California, Berkeley (# 2013-10-5,693).

Birth Outcomes

We assessed the relationship between OGD and four outcomes: *a*) continuous birth weight (grams) among tBW (≥37 completed weeks); *b*) LBW (<2,500 g); *c*) PTB (<37 wk); and *d*) SGA (birth weight less than the U.S. sex-specific 10th percentile of weight for each week of gestation (Talge et al. 2014). Gestational age was estimated by subtracting the LMP date from the date of birth.

Exposure Assessment

Active and inactive oil and gas well records including monthly production data were downloaded from the CA Division of Oil, Gas and

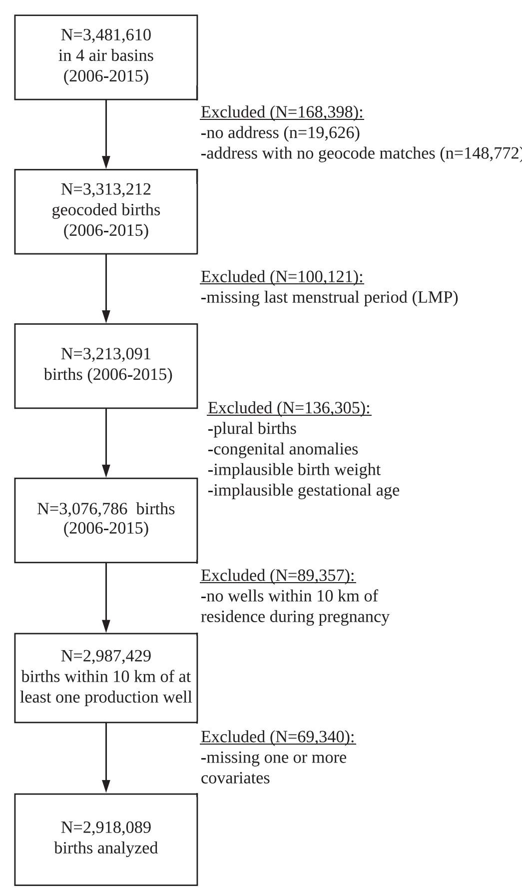

Figure 1. Flow diagram of study population development and exclusion criteria applied.

Geothermal Resources website (CA DOGGR) in December 2015 (the division has been renamed to the CA Geologic Energy Management Division, CalGEM, as of January 2020). We assessed exposure to inactive wells because previous studies have found fugitive methane emissions from abandoned production wells that have not been plugged or were improperly plugged (Boothroyd et al. 2016; U.S. EPA 2018; Kang et al. 2016). VOCs, such as BTEX and toxic air contaminants, are likely coemitted with methane (LACDPH 2018; SCAQMD 2019), and exposure to VOCs, including BTEX and formaldehyde, are associated with adverse birth outcomes (Bolden et al. 2015; Chang et al. 2017; Maroziene and Grazuleviciene 2002). Some of the 224,695 wells in the data set began producing as far back as 1900. The DOGGR data included well latitude/longitude and monthly production volume (barrels of oil and/or cubic meters of natural gas). We defined a production well as active if it produced at least one unit of oil or gas in a given month; production wells could transition between active and inactive status across the study period. We combined these well data with mothers' residential addresses at the time of delivery, date of conception (defined as LMP), and date of delivery to assign prenatal exposure to oil and gas wells.

Study participants lived within 10 km of at least one active or inactive well at the time of delivery. We classified women who had at least one active or inactive well within 1 km of their residential address as exposed (Figure 2); prior literature suggests highest exposure to OGD-related hazards within this radius (Boyle et al. 2017; McKenzie et al. 2012; Meng 2015; Walker Whitworth et al. 2018, 2017). We selected the 1-km buffer presuming that localized air pollution is likely the greatest contributor to OGD-related exposure in CA. We used the short distance to minimize the impact of dispersion and the contribution of exposure from other sources of air pollution. We calculated exposure across the entire pregnancy and by trimester to examine potential critical windows of prenatal exposure.

Exposure to active wells was characterized by oil and gas production volume during pregnancy and exposure to inactive wells by well count. Total production volume exposure from active wells within 1 km was derived by summing monthly barrels of oil and

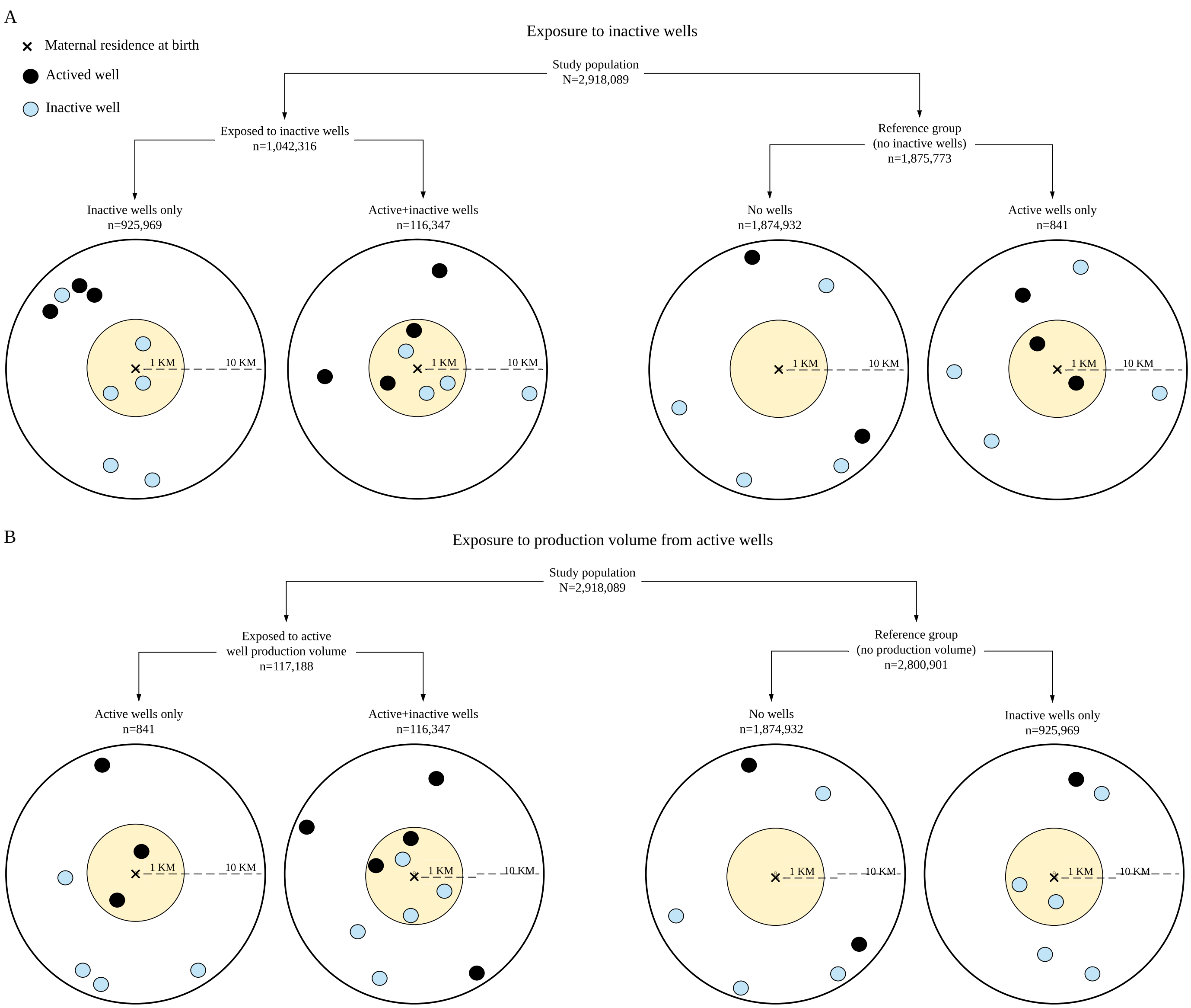

Figure 2. Schematic of definition of exposure and reference groups for inactive well count (A) and active well production volume (B). For each exposure metric, exposure was based on the presence of inactive or active wells within the 1 km buffer. Observations without the specific well type for each metric were assigned into the reference category.

barrels of oil equivalent (BOE) of natural gas. Production volume from oil and gas wells were summed because 95% of gas wells also produced oil (i.e., wet gas) and gas-only wells did not produce significant amounts of gas. Production volume was summed as shown in Equation 1:

$$\text{Total production volume}_j = \sum_{i=1}^{n}\sum_{k=k}^{l}\text{Prod(oil)}_{ik} + \sum_{i=1}^{n}\sum_{k=k}^{l}\text{Prod(gas)}_{ik}/6,$$

where Prod(oil)_{ik} was the production volume of oil (in barrels), and Prod(gas)_{ik} was the production volume of gas (in thousand cubic feet, mcf) at well i during month and year k of mother j's entire pregnancy or trimester. K is the month and year of conception or beginning of a trimester, and l is the month and year of delivery or end of a trimester. K has a minimum value of 1 equal to January 2005, and l has a maximum of 124 or December 2015. Gas production volume was converted from the original units to BOE by dividing by 6 because 6,000 cubic feet $(\text{mcf}) = 1$ BOE (Bonavista Energy Corporation 2018; Schmoker and Klett 2005). The total production volume for the first and last month of the entire pregnancy or trimester was also weighted by the proportion of the month the mother was pregnant.

We calculated the number of inactive wells within 1 km of a mother's residence during her pregnancy by subtracting the number of active wells from the total number of wells within 1 km. For analysis, we first normalized production volume by the number of days of the entire pregnancy or within each trimester by dividing production volume by the total number of days and then categorized exposure to production volume of active wells based on the exposure distribution as: *a*) no active wells, *b*) 1–100 BOE/d (moderate), and *c*) more than 100 BOE/d (high). We similarly categorized exposure to inactive wells as: *a*) no inactive wells, *b*) 1 inactive well, *c*) 2–5 inactive wells, and *d*) 6 or more inactive wells. The production volume was normalized to prevent bias from neonates born later because their exposure period was longer. Given a lack of *a priori* knowledge about the production volume or inactive well count that might constitute a harmful exposure, we selected these categories based on the distribution of each exposure metric across cases and noncases to ensure sufficient overall sample size and number of cases in each exposure group. The exposure variables were not modeled as continuous because the distribution was right skewed (Table S2). Both active and inactive well exposure variables were included in all regression models. The exposure variables were generated in R version 3.3.1 (R Development Core Team).

Covariates

Individual-level covariates that were identified *a priori* as significant predictors of our outcomes and potential confounders based on prior studies were derived from the CDPH birth records. Infant covariates included sex, month (categorical) of birth, and year of birth (categorical) to control for seasonal and secular trends. Maternal covariates included age in years (<20, 20–24, 25–29, 30–34, 35+), race/ethnicity (non-Hispanic white, black, American Indian, Asian-Pacific Islander, unknown or other, and Hispanic), educational attainment (<high school, high school graduate/GED, some college, college+), Kotelchuk index of prenatal care (inadequate, intermediate, adequate, adequate+) (Alexander and Kotelchuck 1996; Kotelchuck 1994), and parity (nulliparous vs. multiparous). For maternal race/ethnicity, American Indian, unknown, and other were combined into one category due to the small number of women in each group. We included mean-centered and mean-centered squared variables for gestational age in the tBW model to allow for nonlinearity.

We also integrated area-level variables, including indicators for air basin and census tract-based urban/rural status, modeled nitrogen dioxide (NO_2) concentrations, and a measure of income concentration. These covariates accounted for neighborhood and regional differences in air quality, economic activity, and emission sources (Arruti et al. 2011; Finkelstein et al. 2003; O'Neill et al. 2003; Wunderli and Gehrig 1990; Zhao et al. 2009). We used 2014 air basin boundaries designated by the California Air Resources Board (CARB 2014), which coincide with county boundaries and roughly delineate areas with similar air quality, meteorology, and geography. We used U.S. Census urban areas [defined as a densely developed territory consisting of urbanized areas of 50,000 or more and urbanized clusters with between 2,500 and 50,000 people (U.S. Census Bureau 2010)] to designate census tracts as urban or rural. Using 2010 boundaries, we categorized census tracts as urban if 60% or more of the tract overlapped with an urban area. We assigned, based on LMP year, tract-level annual ambient NO_2 concentration as a proxy for traffic-related air pollution (Kim et al. 2018). Last, we used the Index of Concentration at the Extremes (ICE) for income as a measure of neighborhood relative deprivation or affluence based on household income by census tract (Massey 1996). ICE provides information about concentration of privilege and deprivation of communities and has previously been associated with infant mortality (Krieger et al. 2016). ICE ranges from -1 to 1, where negative values indicate a concentration of household incomes in the lower 20th percentile of area median household income, whereas positive values indicate a concentration of household incomes in the higher 80th percentile. We calculated ICE using 2006–2010 ACS and 2011–2015 ACS metropolitan area median household income to establish percentile cutoff values that account for regional differences in the cost of living. These values were then used in combination with census tract median household income from the ACS data of the vintage of the birth year to assign a tract-level ICE value to each birth. For tracts that were not within metropolitan areas, county-level household income cutoffs were used. ICE was categorized by quartile and this categorical variable was included in adjusted models.

Statistical Analyses

Statistical analyses were conducted in SAS 9.4 (SAS Institute Inc.). All models were adjusted for individual-level and community-level covariates selected *a priori*: neonate sex, gestational age (tBW model only), month and year of birth, maternal age, race/ethnicity, educational attainment, Kotelchuck index, urban indicator, air basin, NO_2, and ICE for income. Generalized estimating equations were used to account for clustering of mothers within census tracts (Hubbard et al. 2010). Observations with any missing covariate were removed from analyses.

Initial analyses assessed exposure across the entire pregnancy and then during each trimester for the entire study population across the four air basins. Statistical significance was assessed at $\alpha = 0.05$. Effect modification (EM) of exposure to active wells by urban/rural status (primary), maternal race/ethnicity, and air basin (both secondary) was evaluated via stratification. We report the strata-specific effect estimates and confidence intervals derived from this methodology. To test the heterogeneity between strata-specific estimates, we modeled interaction terms to derive Bonferroni adjusted p-values for two-sample z-tests using model-estimated beta coefficients and variances (Buckley et al. 2017; UCLA: Statistical Consulting Group). These EM p-values indicate whether the strata-specific associations are statistically significantly different from each other or the referent group. Non-Hispanic whites were used as the referent in heterogeneity tests for the other racial/ethnic groups because higher rates of adverse birth outcomes have been observed among people of color in

Table 1. Neonate, maternal, and area-level characteristics of births by oil and gas well production volume category, California 2006–2015. Prepregnancy BMI and smoking during pregnancy were available for 2007–2015 births (2006 births excluded from the missing category).

Variable	*n* (%)	No BOE (*n* = 2,866,735)	Production volume 1–100 BOE/day (*n* = 70,615)	GT 100 BOE/day (*n* = 50,079)	*p*-Value[a]
Neonate characteristics					
Mean birth weight [g (mean ± SD)]	2,987,429 (100)	3,327 ± 528	3,318 ± 527	3,316 ± 527	<0.0001
Mean gestational age [weeks (mean ± SD)]	2,987,429 (100)	39 ± 2	39 ± 2	39 ± 2	<0.0001
Sex					
Female	1,456,548 (49)	49	48	49	0.2879
Male	1,530,866 (51)	51	52	51	—
Missing[b]	15 (<1)	100	0	0	—
Birth month					
January	244,433 (8)	8	8	8	0.3261
February	224,691 (8)	8	8	8	—
March	245,683 (8)	8	8	8	—
April	233,297 (8)	8	8	8	—
May	242,652 (8)	8	8	8	—
June	241,962 (8)	8	8	8	—
July	260,028 (9)	9	9	9	—
August	269,714 (9)	9	9	9	—
September	266,586 (9)	9	9	9	—
October	261,399 (9)	9	9	9	—
November	245,566 (8)	8	8	8	—
December	251,418 (8)	8	8	8	—
Birth year					
2006	320,330 (11)	11	10	12	<0.0001
2007	320,698 (11)	11	11	12	—
2008	312,732 (10)	10	10	11	—
2009	300,201 (10)	10	10	10	—
2010	290,469 (10)	10	10	10	—
2011	288,006 (10)	9	10	9	—
2012	288,855 (9)	10	10	9	—
2013	287,425 (10)	10	10	9	—
2014	293,637 (10)	10	10	9	—
2015	285,076 (10)	9	9	9	—
Maternal Characteristics (%)					
Education					
<High school	764,090 (26)	26	31	21	<0.0001
High school diploma/GED	764,206 (26)	26	23	21	—
Some college	724,574 (25)	25	22	23	—
College+	665,993 (23)	23	24	35	—
Missing[b]	68,566 (2)	95	3	2	—
Age at delivery					
<20	252,857 (8)	9	9	6	<0.0001
20–24	651,062 (22)	22	21	18	—
25–29	809,072 (27)	27	27	25	—
30–34	754,714 (25)	25	26	29	—
35+	519,700 (17)	17	17	22	—
Missing[b]	24 (<1)	92	8	0	—
Race/ethnicity					
Asian/Pacific Islander	356,603 (12)	12	11	13	<0.0001
Black	154,047 (5)	5	6	9	—
Hispanic	1,673,517 (56)	56	59	47	—
Other	84,384 (3)	3	2	4	—
White	718,878 (24)	24	22	27	—
Kotelchuck index					
Inadequate	351,729 (12)	12	13	12	<0.0001
Intermediate	349,946 (12)	12	12	9	—
Adequate+	905,545 (30)	30	29	34	—
Adequate	1,380,209 (46)	46	46	45	—
Parity					<0.0001
Nulliparous	1,154,875 (39)	39	40	44	—
Multiparous	1,831,556 (61)	61	60	56	—
Missing[b]	998 (<1)	93	4	3	—
Mean pre-pregnancy BMI[c] (SD)	2,472,066 (93)	26 ± 6	26 ± 6	25 ± 6	<0.0001
Missing[b]	195,033 (7)	94	4	2	—
Smoking during pregnancy[c]					<0.0001
Smoked	49,461 (2)	2	1	1	—
Did not smoke	257,7903 (97)	98	99	99	—
Missing[b]	39,735 (1)	92	5	3	—
TRI facility: 1+within 1 km	48,189 (2)	2	4	3	<0.0001

Table 1. (*Continued.*)

Variable	*n* (%)	No BOE ($n = 2{,}866{,}735$)	Production volume 1–100 BOE/day ($n = 70{,}615$)	GT 100 BOE/day ($n = 50{,}079$)	*p*-Value[a]
Area-level characteristics (%)					
Mean NO_2 [ppb (mean ± SD)]	2,987,408 (99)	16 ± 7	18 ± 7	19 ± 5	<0.0001
Missing[b]	21 (<1)	95	0	5	—
Urban	2,651,066 (89)	89	87	97	—
Air Basin					
Sacramento Valley	296,668 (10)	10	1	0.5	<0.0001
San Joaquin Valley	563,276 (19)	19	21	4	—
South Central Coast	178,647 (6)	6	6	1	—
South Coast	1,948,838 (65)	65	72	94	—
ICE					
Quartile 1–poverty	731,431 (25)	25	31	27	<0.0001
Quartile 2	731,403 (25)	25	23	19	—
Quartile 3	730,283 (25)	25	19	23	—
Quartile 4–wealth	724,972 (25)	25	27	31	—
Missing[b]	217 (<1)	76	9	15	—
Oil/gas wells					
Mean inactive well count (mean ± SD)	2,987,429 (100)	0	89 ± 111	160 ± 191	<0.0001
Mean active well count	2,987,429 (100)	0	4 ± 4	32 ± 27	<0.0001
Mean production volume (BOE)/d (mean ± SD)	2,987,429 (100)	0	26 ± 26	599 ± 711	<0.0001

Note: —, No data; BOE, barrels of oil equivalent; ICE, Index of Concentration at the Extremes.
[a]ANOVA or chi-square test.
[b]Distribution of missingness across categories of production volume rather than percent missing in each production volume category.
[c]No covariate data available for 2006 (not included as missing), $n = 2{,}667{,}099$ births between 2007 and 2015.

comparison with whites (Bryant et al. 2010; Teitler et al. 2007). Sacramento Valley was the referent in heterogeneity tests for the other air basins because exposures to active wells were limited to rural areas of that basin, where there were also fewer births. For the effect modification analyses with race/ethnicity and air basin, only exposure across the entire pregnancy was evaluated because trimester-specific estimates were similar to those for the entire pregnancy.

We conducted two sensitivity analyses with exposure variables across the entire pregnancy only. Mothers' smoking status during pregnancy and prepregnancy body mass index (BMI) were not collected by CDPH in 2006, so we conducted sensitivity analyses with both of these variables in one model for 2007–2015. Only 2% of mothers smoked during pregnancy among our study population within our study period (prevalence of smoking during pregnancy in CA was 2.5% in 2015) (CDPH 2015). Additionally, we considered potential confounding from other industrial sources of air pollution and included a binary variable for exposure to air pollution from other facilities (e.g., refineries, power plants, metal mining facilities) monitored for emissions, including air toxics by the CARB (CARB 2017) within 1 km (referred to as TRI facilities). Only $\sim 2\%$ of mothers resided within proximity to TRI facilities during our study period.

We tested for multicollinearity between all model variables by calculating the variance inflation factors (Schreiber-Gregory 2012), none of which were high (i.e., >10). To assess residual spatial dependence, we generated semivariograms of regression residuals plotted against distance between mothers' residential addresses (Le Rest et al. 2013; SAS) (Figure S3). The residuals appeared randomly distributed, suggesting spatial autocorrelation was likely controlled for by the study design and inclusion of spatial covariates (e.g., NO_2) in regression models.

Results

Our study included 2,918,089 births in CA between January 2006 and December 2015 located in four air basins: the Sacramento Valley, San Joaquin Valley, South Central Coast, and South Coast. The overall mean birth weight was 3,327 g [standard deviation (SD) = 528] (Table 1). Five percent ($n = 148{,}100$) of births were LBW, 7% ($n = 199{,}460$) preterm, and 12% SGA ($n = 337{,}943$). A maximum of 1,189 inactive wells and 441 active wells were located within 1 km of mothers' residences during pregnancy. On average, mothers exposed to moderate production volume (1–100 BOE/d) had 89 inactive and 4 active wells within 1 km of their home during pregnancy, whereas mothers exposed to high production volume (>100 BOE/d) had an average of 160 inactive wells and 32 active wells within a 1-km buffer. The average moderate total production volume from active wells producing oil and gas during pregnancy was 26 BOE/d, and the average high total production volume was 599 BOE/d. Temporal trends of mean annual production volume and annual rates of the binary birth outcomes showed no distinct patterns in either rural or urban areas (Figure S4A,B). Plots of temporal trends in mean annual production volume and mean annual tBW also did not reveal consistent patterns in either rural or urban areas (Figure S4C,D). The reference (no BOE) and exposed populations were relatively similar in terms of demographic and socioeconomic factors (Table 1). Compared to the reference and moderate production volume groups, mothers in the high production volume category were slightly more educated (35% vs. 23.5%, on average, college or more educated), older (22% vs. 17%, on average, aged 35 or more), more often non-Hispanic (53% vs. 42.5%, on average, non-Hispanic races), more likely to have no previous pregnancies (44% vs. 39.5%, on average, nulliparous), and to reside in urban areas (97% vs. 88%, on average), in the South Coast air basin (94% vs. 68.5%, on average) and in areas with greater wealth (31% vs. 26%, on average, in ICE quartile 4). Finally, babies born to mothers exposed to high production volume weighed on average 2 and 11 grams less than those born to mothers exposed to moderate production volume and reference group, respectively.

Adjusted models generally found no associations between inactive well count and adverse birth outcomes in both rural and urban areas (Figure 3, Tables S1–S2). All statistically significant associations indicated modestly decreased odds of LBW and PTB (0.96–0.97) (Figure 3A,B; Table S1) or minimally increased birth weight (4–5 g) (Figure 3D; Table S2) related to increased inactive OGD well exposure. Models based on trimester-specific exposures yielded similar estimates across trimesters for all four birth outcomes (Table S1–S2).

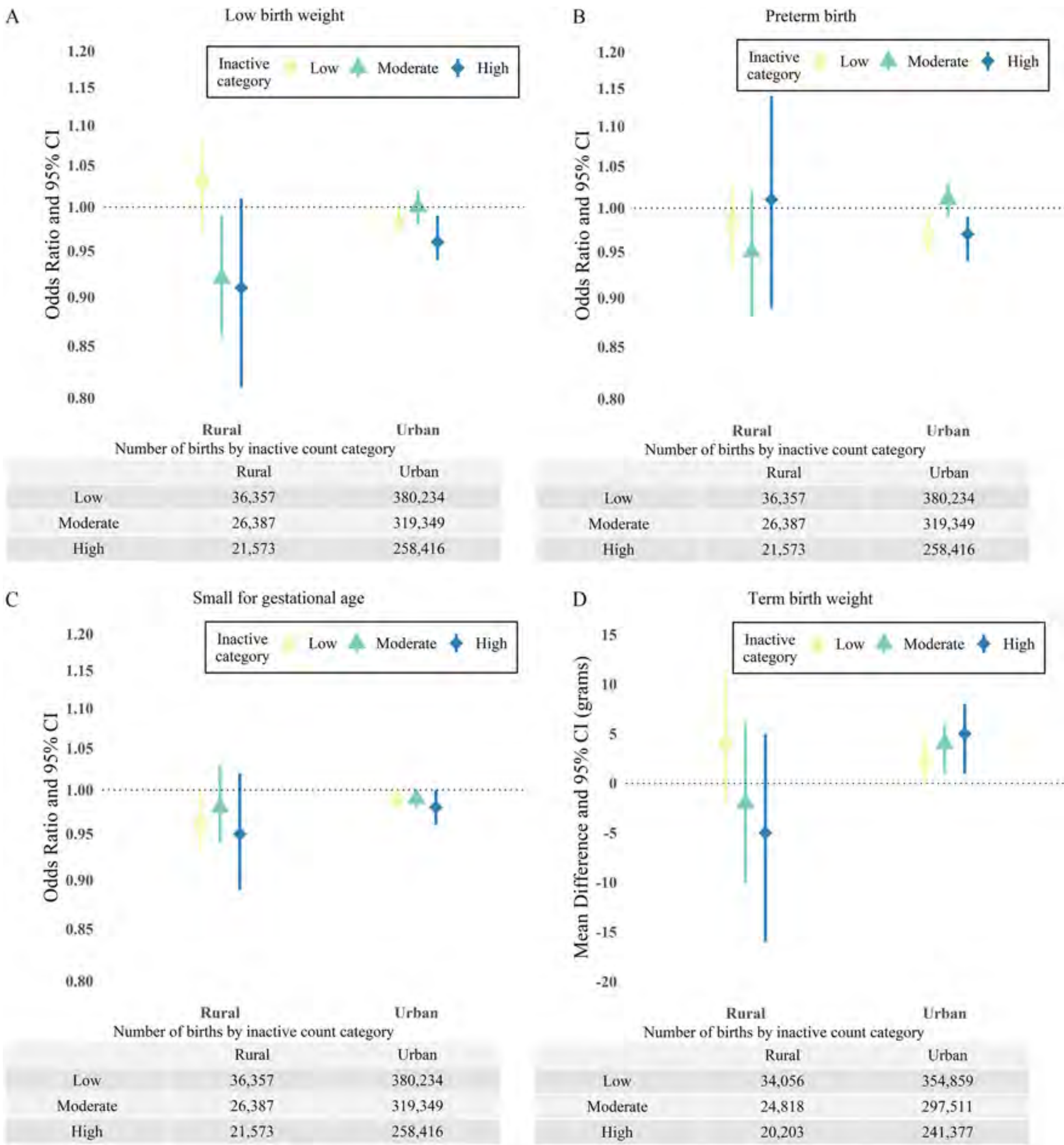

Figure 3. Plots of rural vs. urban odds ratios or mean difference in birth weight (grams) and 95% confidence interval (CI) for associations between exposure to low, moderate, and high counts of inactive wells across the entire pregnancy and low birth weight (A), preterm birth (B), small for gestational age (C), and continuous term birth weight (D). Logistic regression models adjust for inactive well count, child's sex, birth month and birth year, and maternal education, age, race/ethnicity, Kotelchuck prenatal care index, parity, air basin, NO_2 and ICE for income. In addition to the covariates adjusted for in the logistic regression models, the linear regression models also adjusted for gestational age. All *y*-axes are on the logarithmic scale except for on the term birth weight plot. Numerical values plotted here can be found along with estimates for the three trimesters and *p*-values for statistical tests for effect modification in Tables S1–S2.

For exposures to production volume from active wells in unstratified models, we observed significant associations between production volume and LBW and SGA (Table S3). When we stratified models by the urban indicator, we observed significant effect modification with stronger associations between high production volume and LBW ($p = 0.01$, Table S4) and tBW ($p = 0.001$, Table S7) in rural areas (Figure 4). Compared to the reference group, the odds ratio for LBW was 1.11 [95% confidence interval (CI): 0.97, 1.27] (Table S4) and the OR for SGA was 1.07 (95% CI: 0.97, 1.19) (Table S6) with exposure to moderate production volume across the entire pregnancy in rural areas vs. ORs of 1.04 (95% CI: 1.00, 1.09) and 1.03 (95% CI: 1.00, 1.07), respectively, in urban areas (Figure 4A,C). Exposure to high production volume was associated with an OR of 1.40 (95% CI: 1.14, 1.71) for LBW and an OR of 1.22 (95% CI: 1.02, 1.45) for SGA in rural areas vs. ORs of 0.99 (95% CI: 0.95, 1.04) and 1.04 (95% CI: 1.01, 1.07), respectively, in urban areas (Figure 4A,C; Tables S4, S6). Exposure to high production volume was also associated with decreased tBW (mean difference = −36 g; 95% CI: −54, −17) for the rural stratum in comparison with the urban stratum (mean difference = 1 g, 95% CI: −5, 8) (Figure 4D; Table S7). For LBW, SGA, and tBW, the strength of the associations increased with higher production volume among the rural, but not the urban, population. In general, exposure to production volume throughout pregnancy was not associated with PTB within rural or urban populations (Figure 4B; Table S5). Models based on trimester-specific exposures yielded similar estimates and EM *p*-values for all birth outcomes (Tables S4–S7), except the third trimester for PTB, where exposure to moderate production volume was associated with increased odds of PTB (OR = 1.06; 95% CI: 1.02, 1.11) and high production volume was associated

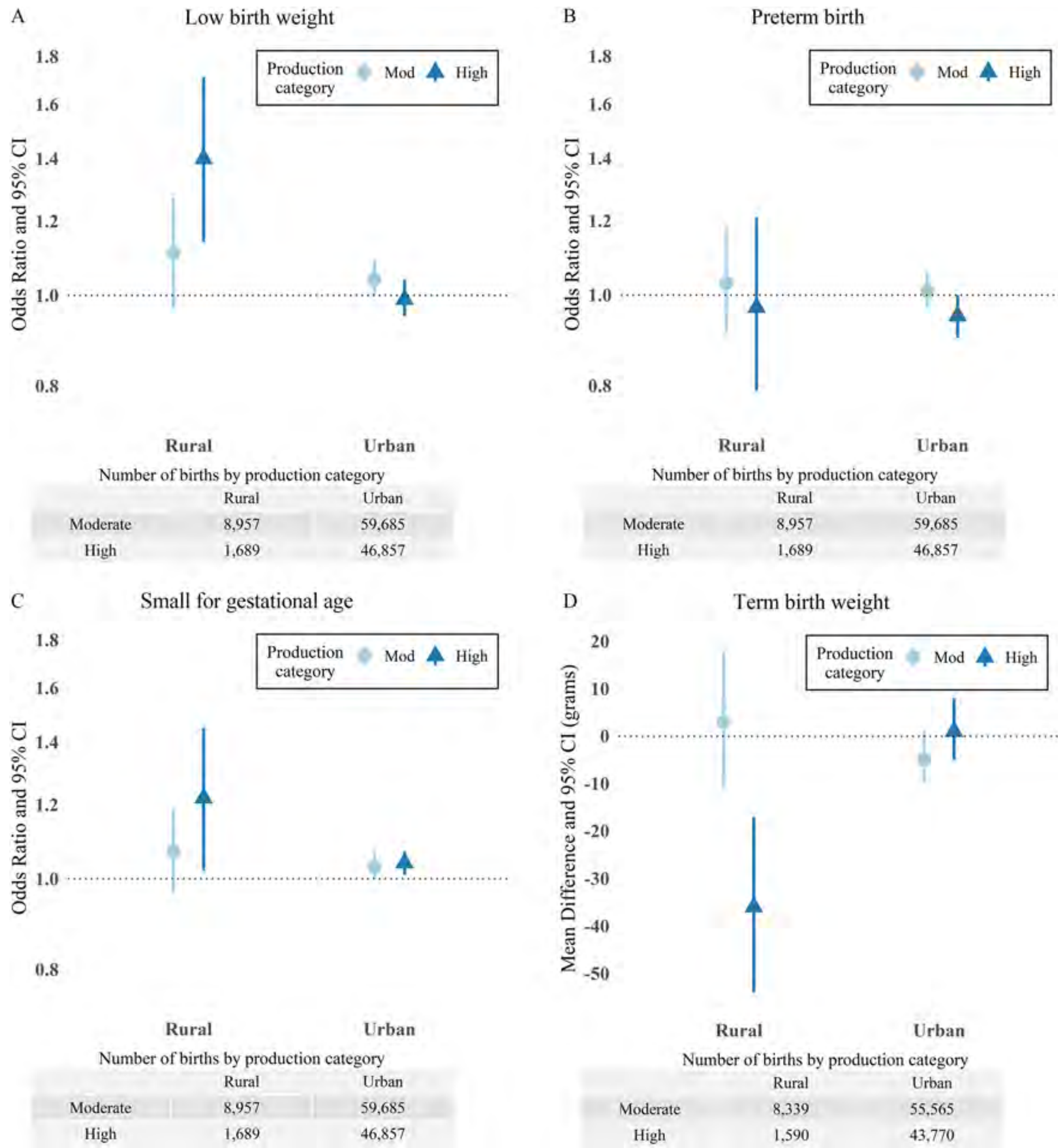

Figure 4. Plots of rural vs. urban odds ratios or mean difference in birth weight (grams) and 95% confidence interval (CI) for associations between exposure to moderate and high production volume across the entire pregnancy and low birth weight (A), preterm birth (B), small for gestational age (C), and continuous term birth weight (D). Logistic regression models adjust for inactive well count, child's sex, birth month and birth year, and maternal education, age, race/ethnicity, Kotelchuck prenatal care index, parity, air basin, NO_2 and ICE for income. In addition to the covariates adjusted for in the logistic regression models, the linear regression models also adjusted for gestational age. All *y*-axes are on the logarithmic scale except for on the term birth weight plot. Numerical values plotted here can be found along with estimates for the three trimesters and *p*-values for statistical tests for effect modification in Tables S4–S7.

with decreased odds of PTB in urban areas (OR = 0.82; 95% CI: 0.77, 0.88) (Table S5).

Maternal race/ethnicity (Tables S8–S9) and air basin (Tables S10–S11) did not significantly modify associations between exposure to active well production volume and birth outcomes. Heterogeneity tests were only conducted on the rural population because the effect sizes across outcomes were greater than those of the urban population. Nearly all strata-specific effect estimates included the null and all EM *p*-values from heterogeneity tests were insignificant across all outcomes.

Sensitivity analyses that included: *a*) prepregnancy BMI and smoking during pregnancy for 2007–2015 births (Table S12) and *b*) exposure to TRI facilities (Table S13) did not change effect estimates by more than 10%.

Discussion

CA's OGD primarily uses conventional drilling and enhancement methods and, to a much lesser degree, HF. To our knowledge, our study is the first to quantify prenatal exposures to both inactive wells and cumulative oil and gas production volume from active wells in proximity to pregnant women and to evaluate differences in associations by rural vs. urban areas in CA. In rural areas, we found that exposure to high production volume was significantly associated with increased odds of LBW and SGA and decreased tBW in comparison with the nonexposed group. In urban areas, exposure within 1 km of high production volume relative to no exposure was only significantly associated with increased odds of SGA; effect estimates for exposure to moderate production volume in rural and urban areas were all insignificant.

One prior study, by McKenzie et al. (2019), evaluated urban/rural residential status as an effect modifier. Although that study examined birth defects, the authors found significantly increased odds for four congenital heart defects in the medium and highest exposure groups (based on an intensity-adjusted inverse-distance weighted well-count metric) relative to the lowest group in rural areas (McKenzie et al. 2019); no significant associations were observed for birth defects in urban areas. These rural vs. urban differences in effect estimates align with the stronger effect estimates we observed in rural areas in CA for LBW and tBW. McKenzie et al. (2019) also discovered a potential additive effect from other sources of air pollution besides OGD in their analysis. Here, we considered residual confounding from TRI facilities within 1 km, but inclusion of this covariate did not change the rural/urban strata-specific effect estimates. Nevertheless, there may be residual confounding from other sources of air or drinking water pollution that we could not account for in our analysis. For example, the ratio of produced water from OGD (which can contain naturally occurring or injected organic/inorganic chemicals, chemicals that are reaction byproducts, and radioactive materials) to oil and gas extracted increases with well age (Veil et al. 2004). Certain chemicals from produced water could evaporate into the air or percolate into groundwater sources, depending on disposal methods (Long et al. 2015a). Air and water pollution concentrations could differ regionally based on dispersion and hydrological transport patterns. Additionally, individual factors that we could not measure in our study, such as maternal occupation, housing quality, indoor air quality, dependence on groundwater sources for drinking water, and underlying population sensitivity to OGD-related pollutants may have contributed to observed differences in effect estimates between rural and urban settings. In the air pollution literature, the exposure–response relationship between cardiovascular disease mortality and $PM_{2.5}$ is relatively steep at low levels of exposure but flattens out at higher levels (Pope et al. 2009; Smith and Peel 2010). Such exposure–response relationships could apply to the OGD setting where urban dwellers may be less affected by OGD-specific pollutants because OGD as an emission source contributes a relatively small percentage to ambient air pollution levels in urban areas, which tend have higher pollutant concentrations overall from diverse mobile and stationary sources. Indeed, average NO_2 levels among urban areas in our study were double that of rural areas.

Results from our analysis align with prior studies that observed decreased birth weight associated with maternal exposure to OGD activities (Currie et al. 2017; Hill 2018; Stacy et al. 2015). However, associations between exposure to OGD and LBW and SGA from other studies have been mixed, with increased odds (Stacy et al. 2015) or incidence probability (Currie et al. 2017; Hill 2018) as well as decreased odds (McKenzie et al. 2014) or no associations (Casey et al. 2015; Whitworth et al. 2017). Although the mechanisms by which OGD may adversely affect birth weight outcomes remain uncertain, air pollution and noise may be possible pathways that affect maternal health during pregnancy. During production, operation of various ancillary equipment (e.g., wellhead compressors, pneumatic devices, separators, and dehydrators) to collect and process oil and gas generate air pollutants (Garcia-Gonzales et al. 2019). Multiple VOCs have been measured at oil and gas wellheads and off-site, including BTEX and formaldehyde. At ambient levels, BTEX and formaldehyde have been linked to significant decreases in birth weight (Bolden et al. 2015; Chang et al. 2017; Maroziene and Grazuleviciene 2002). Flaring also occurs with oil-producing and horizontally drilled wells (Franklin et al. 2019) and can contribute to spikes in $PM_{2.5}$, black carbon, and VOCs during production (Allshouse et al. 2019; Franklin et al. 2019). Relative to other phases of OGD, excessive noise is minimized during production (Allshouse et al. 2019; Hays et al. 2017). However, noise from compressor stations often exceed the World Health Organization's recommended 55 dBA at night (Hays et al. 2017) and noise above 65 dBA was measured 20% of the time between 1900 hours and 0700 hours (7:00 P.M. and 7:00 A.M.) in one study (Allshouse et al. 2019). Excessive noise can lead to annoyance and impaired sleep quality (Hays et al. 2017), which have been linked to LBW (Abeysena et al. 2010; Owusu et al. 2013) and PTB (Li et al. 2017).

Unlike previous studies, we found no significant association between exposure to active wells and PTB except in the third trimester in urban areas where moderate exposure appeared harmful and high exposure protective. Exposure to OGD was associated with modestly decreased odds for PTB (Stacy et al. 2015) and increased odds (Casey et al. 2015) in Pennsylvania and increased odds in Texas (Walker Whitworth et al. 2018; Whitworth et al. 2017). The two Pennsylvania studies were conducted in different regions of Pennsylvania and among different populations [general for Stacy et al. (2015) and patients served by one health-care provider for Casey et al. (2015)]. The inverse association in the Stacy et al. (2015) analysis was only observed for the second quartile of exposure in comparison with the lowest quartile, whereas the association increased with greater exposure (quartiled) in the Casey et al. (2015) study. In Texas, the association was only significant with the highest level of exposure within 10 miles (Walker Whitworth et al. 2018) and the first and second trimesters with exposure within half a mile (Whitworth et al. 2017). Associations for PTB appear to vary by level of exposure as well as trimester. We only observed significant associations—increased odds with moderate exposure and decreased odds with high exposure—in urban areas in the third trimester. Previous studies on air pollution and birth outcomes have suggested that the first and third trimesters are critical windows of exposure for LBW and PTB (Ritz and Wilhelm 2008; Woodruff et al. 2009). Additionally, the significant inverse association between high OGD exposure and PTB in urban areas may reflect residual confounding or live-birth bias. Other socioeconomic status characteristics that were not controlled for in our models could have led to underlying differences among urban dwellers or their exposure patterns. Moreover, if more highly exposed or more vulnerable mothers were less likely to become pregnant or more likely to experience fetal loss, a so-called "depletion of susceptibles" could have occurred (Raz et al. 2018), and a seemingly protective effect would then be observed. Although we could not evaluate fertility patterns or spontaneous abortion in our analysis, a study in Ecuador observed greater odds of spontaneous abortion among women who lived within 5 km downstream of an oil field in comparison with those who lived at least 30 km upstream of an oil field (San Sebastian et al. 2002).

The inconsistent results across studies may reflect differences in statistical and exposure assessment methods, study population demographics, and OGD infrastructure. First, to limit unmeasured confounding, our analyses restricted the study population to those individuals living within 10 km of at least one active or inactive well at the time of delivery. Similar to Whitworth et al. (2017), we specified the unexposed group as those pregnancies with some well activity, but no well activity within 1 km. Besides their exposure, the control and exposed groups are likely more similar to each other on other characteristics (e.g., unmeasured socioeconomic factors) than a control group selected from greater distances or other regions. Second, we applied a 1-km buffer for our exposure metric without weighting, i.e., without up-weighting wells at a shorter distance from maternal residences. Previous studies used inverse distance weighting (McKenzie et al. 2014; Stacy et al. 2015) or inverse distance squared weighting (Casey et al. 2015; Walker Whitworth et al. 2018, 2017) but often included wells beyond our 1-km buffer.

Inverse distance weighting has been applied in many air pollution studies (de Mesnard 2013). Although air pollution may be a large contributor to OGD-related exposure, we did not assume that it is the only OGD-related hazard, and within such a short distance (1 km), dispersion patterns of OGD pollutants may be relatively uniform. Therefore, we weighted all wells equally within the 1-km buffer. Third, we examined separate effects of inactive wells and active well production volume, whereas prior studies have not considered inactive wells separately and often only examined the density of (McKenzie et al. 2014; Stacy et al. 2015; Whitworth et al. 2017) or total production volume from unconventional wells (Casey et al. 2015; Walker Whitworth et al. 2018). Including both inactive and active wells allowed us to distinguish possible differential effects by well type. Fourth, our CA study population was more racially and ethnically diverse than those in other studies conducted in Colorado and Pennsylvania, which may contribute to differences in analytical results. Finally, California's OGD infrastructure is older than infrastructure in other states and utilizes less HF in comparison with OGD in Pennsylvania, Colorado, and other states where production infrastructure is newly established (Long et al. 2015b). These regional differences in OGD infrastructure may affect the type of hazards associated with them and their implications for maternal health and birth outcomes.

Our study is the first to highlight differences in potential health impacts of exposure to active OGD based on total production volume from both oil and gas wells and inactive wells. We did not, however, directly measure OGD environmental impacts via, for example, air or drinking water monitoring near active or inactive wells. Several OGD-related hazards—air toxics, water pollutants, noise, excessive lighting—may elicit a variety of biological responses, but our exposure measure precluded identification of specific pathways through which OGD may affect birth outcomes. Further, the cumulative exposure–response curve of all of the potential hazards and health outcomes may differ than that for each individual hazard separately. For example, living in proximity to oil and gas fields and seeing the active rigs daily might induce stress, worry, and lack of sleep (Ferrar et al. 2013; Hirsch et al. 2018; Long et al. 2015a; Palagini et al. 2014). However, individuals may habituate, leading to biological responses that may peak and level off (Basner et al. 2011), whereas we might expect a linear exposure–response related to air pollution exposures.

We observed some modest inverse associations between inactive wells and birth outcomes, primarily in urban areas. Inactive wells can pose risks in several ways. To date, excessive fugitive methane emissions have been measured at abandoned (unplugged) well sites, with higher concentrations detected at sites with compromised wells (Boothroyd et al. 2016; Kang et al. 2016). Residual off-gassing of air contaminants such as BTEX could also occur, which has prompted the South Coast air district and DOGGR to begin to collect air toxics and VOCs emissions data (LACDPH 2018; SCAQMD 2019; California AB1328). Of greater concern is contamination of potable water sources from subsurface leakage and migration of contaminants through abandoned or idle wells (Long et al. 2015a). In an assessment of groundwater contamination from OGD in Ohio and Texas over more than a decade, abandoned wells accounted for 22% (Ohio) and 14% (Texas) of contamination incidents (Ground Water Protection Council 2011). In CA, idle wells may be repurposed for wastewater disposal or later revitalized with new technologies (Walker 2011). Wells operating with old infrastructure pose greater risks of leakages through the well casing and cement barriers (Ingraffea et al. 2014). HF could also increase the risk of surface or groundwater contamination via abandoned wells due to hydrological pressure changes; in one rare incident, an abandoned well in Pennsylvania produced a 30-foot geyser of brine and gas for more than a week after a nearby gas well underwent HF (EPA 2016). We may not have observed any consistent or significant associations between exposure to inactive wells and adverse birth outcomes because we were not able to capture these nuanced exposure pathways with well count alone, leading to potential exposure misclassification.

Other limitations include our inability to adjust for several individual-level factors. Due to lack of data linkage, we could not control for the correlation between siblings (though we do include parity in all models) or maternal mobility during pregnancy. Birth records did not include a linking variable for siblings and only documented the residential address at time of birth. Previous studies on impacts of residential mobility during pregnancy suggest that ignoring residential mobility may lead to modest bias in associations toward the null or result in nondifferential exposure misclassification (Chen et al. 2010; Hodgson et al. 2015; Lupo et al. 2010; Pennington et al. 2017). However, exposure estimates based on addresses captured at birth vs. conception have been highly correlated (Chen et al. 2010; Lupo et al. 2010; Pennington et al. 2017). Across studies, $\leq 30\%$ of mothers moved during pregnancy and moving distances were relatively short and within the same county (Bell and Belanger 2012; Chen et al. 2010; Hodgson et al. 2015; Lupo et al. 2010; Miller et al. 2010; Pennington et al. 2017). The extent of misclassification error depends on the spatial variability in the exposure (Hodgson et al. 2015). Additionally, exposure misclassification may be less prominent in the third trimester. Across environmental epidemiological studies that evaluated the impact of residential mobility on effect estimates by trimester, the highest rates of mobility occurred in the second trimester (Bell et al. 2018; Bell and Belanger 2012). Lowest residential mobility was observed in the first trimester among three studies and in the third trimester among two studies (Bell et al. 2018; Bell and Belanger 2012). Exposure misclassification due to mobility in the third trimester is less likely to be an issue, due to its proximity to the time of delivery, when the maternal residential address is collected and listed on the birth certificate. In addition to residential mobility, maternal occupational mobility should also be considered. One study that evaluated the impact of occupational mobility on air pollution exposure misclassification among Parisian women in the two first trimesters found that mode of transport increased NO_2 exposure in the first trimester (Blanchard et al. 2018). Our study results yielded similar effect estimates across trimesters, suggesting that any bias resulting from maternal residential and occupational mobility is likely nondifferential across trimesters.

In summary, this study expands the current literature on the health implications of OGD. We observed that prenatal exposure to active oil/gas production from both conventional and unconventional wells in CA was associated with adverse birth outcomes, and these associations varied by rural and urban areas. We observed the strongest associations with exposure to high production volume in rural areas. Future studies should consider inactive wells and conduct exposure assessments that collect environmental samples of OGD-related hazards. Such data would greatly improve exposure assignment and advance our understanding of underlying exposure sources and pathways. Additional evaluations of the relationship between oil/gas operator size, pollutant emissions, and frequency and type of violations and health outcomes would also elucidate which types of wells may be of greatest concern. Such data can inform regulatory decisions in terms of prioritizing inspection and pollution monitoring as well as emissions reduction requirements and community exposure reduction strategies.

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Exhibit 12 of 13 - Shamasunder 2018. Community Based Health and Exposure Study

Communication from Public

Name: E&B Natural Resources
Date Submitted: 11/21/2022 03:45 PM
Council File No: 17-0447-S2
Comments for Public Posting: Enclosed are our written comments. Thank you

E&B NATURAL RESOURCES

1608 Norris Road • Bakersfield, CA 93308

October 5, 2022

Honorable Los Angeles City Councilmembers
Energy, Climate Change, Environmental Justice, and River Committee
Submitted electronically at LACouncilComment.com

Re: Oil & Gas Ordinance Draft, related to agenda item 2, Council File 17-0447-S2

Dear Los Angeles City Councilmembers:

E&B Natural Resources (E&B) provides the following comments relating to the Los Angeles City proposed draft Oil & Gas Ordinance.

E&B is a California-based energy producer. We produce over 8,000 barrels of oil per day for Californians including Angelenos. E&B and its affiliates including HBOC complies with rules and regulations administered by multiple agencies at the local, state, and federal levels. We have a personal and collective interest in adhering to California's stringent environmental regulations to protect the safety of our workforce. We are dedicated to producing the cleanest and most environmentally friendly oil and natural gas that meets California climate compliancy. We have over 250 staff working for E&B, many in the Los Angeles area. We also provide monthly royalties to thousands of royalty owners in the local area. We have been a long-time partner to the city, active in the local community and we look forward to continuing to work with LA City on the draft ordinance.

We have all witnessed over these last weeks, months and years (i.e., Ukraine and Russia event, COVID-19, supply chain issues, rising gas prices, etc.) how important it is to be able to source locally and buy locally. California, the fifth largest economy in the world, demands nearly 1.8 million barrels of oil per day and local in-state production only supplies roughly 30% of our state needs. We believe that while demand for the product remains strong, it is best for the local and state economies and the environment to have the ability to procure product locally than from foreign sources including from Ecuador, Saudi Arabia and Russia who don't have the same environmental regulations as California. Our workforce and product have been recognized as critical and essential to our nation and to our state.

We recognize the need for improvement and for change. We believe we can work together to achieve an ordinance that works for the majority of the stakeholders. We appreciate the work staff has done thus far. We offer the following thoughts and recommendations.

NATURAL RESOURCES

1608 Norris Road • Bakersfield, CA 93308

Study Economic and Environmental Impacts. Mitigate for potential unintended consequences.
We recommend the city study the environmental impacts of losing its local production, particularly impacts to air emissions. Where is LA City going to get its oil from? Reducing local production often leads to an increase in foreign imports. California is an energy island and there is no infrastructure like oil pipelines to carry oil into the state from other states. These foreign imports would increase super tanker traffic to our local ports in Long Beach and Los Angeles. According to the South Coast Air Quality Management District, the number one source of toxic pollution in the LA Basin comes directly from port ships including supertankers carrying foreign oil. We also urge the city to study the countries supplying foreign imports, their human rights records and the countries' environmental regulations including Ecuador, Saudi Arabia and Iraq. We also recognize the on-going job transition study, and we would like to see that finalized prior to taking this policy forward. Negative consequences due to the proposed policy should be acknowledged and addressed as part of this overall policy discussion.

Amortization Study and Legal Analysis should be made public by the City Attorney's Office prior to moving forward with this policy.
In the proposed ordinance, the city calls for an amortization period of existing wells and facilities of twenty years. The city, however, has not provided an amortization study to support the 20-year time frame, nor has it explained how such an amortization program is legally authorized for mineral resources. We believe that the city's "potential" amortization program / period has no support in fact or in law and instead serves only to violate E&B and HBOC's constitutionally protected vested rights as well as the rights of the mineral owners. We recommend that the city work with the operators and stakeholders on the amortization study, and we work together to find the right balance of best practices, regulations and good neighbor provisions.

Prohibition on Maintenance Activities is inconsistent with State law and further violates constitutional protections.
The draft ordinance does not allow for maintenance activities which could jeopardize field safety and reliability. There are numerous activities conducted on an oil field to maintain equipment or take other actions to enhance the safe and reliable operation of the field. There are numerous activities that are required by law. Taking away our rights to maintain our wells could pose numerous unintended consequences. We recommend allowing operators to continue to maintain their wells in a safe and responsible manner. Anything less would be reckless and potentially unconstitutional. Let's move forward with smart regulation. We are ready to work with you and City's staff on these specific issues. In fact, we have been working with community, neighborhood councils and local council offices to voluntarily move forward with several best practices and emerging technologies to keep our sites performing optimally. We were the first to implement fence line air monitoring systems, advocate for annual inspections and volunteer for

additional reporting requirements. Please look to our company to be the model for what is possible.

Any Action by City Council's Energy, Climate Change, Environmental Justice, and River Committee is Premature Until CEQA Process is Complete.

The City issued a notice that the Mitigated Negative Declaration (MND) is available for public comment and review, with the 30-day comment period closing on October 17, 2022. The Energy, Climate Change, Environmental Justice, and River Committee's responsibilities include "overall review of environmental impact reports or statements, or of the environmental impact of proposed Council actions that have not been considered as part of a land use decision . . . ." (Resolution, January 12, 2021, City Council Committees.) The City Planning Commission decided not to consider the comments on the MND and indicated that would be considered by the City Council, the decision-making body. Given that the responsibilities of the Energy, Climate Change, Environmental Justice, and River Committee include review of environmental issues for the City Council, the Committee should postpone any action until the CEQA process is complete.

In regard to plugging and abandoning wells, we recommend that you continue to engage operators in these discussions, work with the state agency CalGEM, and stay consistent with state law and the existing state idle well program.

We also incorporate by reference all of the comments submitted by Alston & Bird to the City Planning Commission in its letter dated September 20, 2022 (attached for convenience to this letter).

It is our hope that we can continue to work together towards an improved ordinance that works for all parties. Please do not hesitate to call upon us for additional information. Please use us as a resource. Thank you for your time and consideration of our comments.

Best regards,

Louis Zylstra, PE
Senior Vice President, Los Angeles Basin
E&B Natural Resources

Tel: 714.968.4770
Email: lou.zylstra@ebresources.com

REFERENCES

1. South Coast Air Quality Management District, https://www.aqmd.gov/nav/about/initiatives/clean-port

ALSTON & BIRD

333 South Hope Street, 16th Floor
Los Angeles, CA 90071-1410
213-576-1000 | Fax: 213-576-1100

Nicki Carlsen Direct Dial: **+1 213 576 1128** Email: **nicki.carlsen@alston.com**

September 20, 2022

City Planning Commission
City of Los Angeles
201 N. Figueroa Street
Los Angeles, CA 90012
cpc@lacity.org

Re: CPC-2022-4864-CA; CF No. 17-0447 – September 22, 2022 Hearing

Dear City Planning Commission:

We represent E&B Natural Resources and its affiliated entities (collectively "E&B") regarding the City's proposed ordinance to amend the Los Angeles Municipal Code "to prohibit new oil and gas drilling activities and make existing extraction a nonconforming use in all zones." (City Planning Commission, Regular Meeting Agenda, September 22, 2022.) The proposed ordinance would also "phase out all oil drilling activities in the City of Los Angeles by immediately banning new oil and gas extraction and requiring the abandonment of existing wells after an amortization period." (Id.)

E&B submitted a comment letter as a part of the August 30, 2022, public hearing on this matter to express its opposition to the proposed ordinance. However, the City has not addressed adequately the issues raised in the letter, and appears to be rushing this process forward without fully considering all of the legal implications of adopting this ordinance. The City issued a revised ordinance on September 13, 2022, along with an 893-page staff report, and yet refuses to provide additional opportunity to provide public comment.

We submit these further comments to reinforce E&B's original objections. As described in this letter, the City has not set forth a legitimate basis for its proposed action. E&B urges the City to take additional time to review these issues and to reconsider the proposed ordinance as it is currently drafted.

1. **Approval of the Proposed Ordinance Would Not Be a Legitimate Exercise of the Police Power**

While the City is afforded a fair amount of latitude in adopting land use regulations, the City's police power is not unlimited. The City here fails to demonstrate that the proposed ordinance is reasonably related to the public welfare. See *Associated Home Builders, Inc. v. City of Livermore*, 18 Cal.3d 582 (1976). The City fails to forecast the probable effect of the ordinance, fails to identify the competing interests involved, and fails to justify why the ordinance reflects a reasonable accommodation of competing interests. For example, the ordinance excludes certain uses, but applies to all oil and gas operations across the City without distinguishing among different locations or operations, even though the City acknowledges that some locations are situated in heavy industrial areas. No analysis of the impacts of this ordinance on any specific property has been performed.

2. The City's Proposed Amortization Period is Arbitrary, Unreasonable and Not Supported by any Evidence

The City's proposed ordinance would impose a 20-year amortization period on oil and gas operations, but the City has failed to provide any evidence or factual support for this chosen 20-year period. "[A]n amortization period *is not* an absolute or unqualified defense to a takings claim." *Levin Richmond Terminal Corp. v. City of Richmond*, 2020 U.S. Dist. LEXIS 156103, *36-37, emphasis added. Rather, the legislation must provide a "reasonable amortization period commensurate with the investment involved." *Id.*, quoting *Elysium Institute, Inc. v. County of Los Angeles*, 232 Cal. App. 3d 408, 436 (1991). While it is questionable that amortization would apply at all to oil and gas interests (see below), any amortization process requires factual evidence to demonstrate the property owner's reasonable investment backed expectations are satisfied. The City indicates that it is the process of preparing an amortization report, but that is putting the proverbial cart before the horse. The amortization study needs to be prepared before any amortization ordinance is adopted.

3. The 20-Year Amortization Period is Illusory

The City's proposed ordinance prohibits well maintenance, maintenance that is required to operate the wells. The City claims that it will allow maintenance under certain circumstances, but if any oil and gas operator sought to seek an approval from the City to conduct maintenance based on health and safety purposes, the approval process could extend beyond six months, resulting in "deemed terminated" finding for "discontinued" operations. Thus, by prohibiting maintenance, the City is essentially terminating these uses well before any 20-year period.

4. City's Proposed Ordinance Would Constitute a Taking of Vested Rights in Violation of the U.S. and California Constitutions

The U.S. and California Constitutions provide that private property shall not be taken without just compensation. U.S. Const. amend. V; Cal. Const., Art. 1, § 19. These constitutional protections apply to regulatory takings. *Lucas v. S.C. Coastal Council,* 505 U.S. 1003, 1014 (1992). "The right to remove oil and gas from the ground is a property right." *Maples v. Kern Cty. Assessment Appeals Bd.,* 103 Cal.App.4th 172, 186 (2002). The City's proposed ordinance serves to affect an unconstitutional taking of E&B's property as an oil and gas operator, along with the property of the landowners and the mineral rights holders.

E&B has vested property rights to operate in the City but the proposed ordinance ignores these rights, prohibiting maintenance on the wells, and requiring abandonment of these wells within

20 years or perhaps far less. Again, without an amortization study, it is difficult to understand the City's thinking.

5. Amortization Does Not Apply to the Extraction of Mineral Resources

The City fails to evaluate the legal propriety of establishing an amortization period for the extraction of mineral resources and ignores the legal doctrine that would invalidate this proposed ordinance – the diminishing asset doctrine. *See Hansen Bros. Enters. v. Board of Supervisors*, 12 Cal.4th 533 (1996). The California Supreme Court in *Hansen* recognized the "diminishing asset" doctrine and defined the scope of vested rights for mining, quarrying and other extractive uses, recognizing the unique qualities of extractive uses and holding that it includes an expansion of those uses.

As explained in the context of a quarry, the court in *Hansen* stated:

> The very nature and use of an extractive business contemplates the continuance of such use of the entire parcel of land as a whole, without limitation or restriction to the immediate area excavated at the time the ordinance was passed. A mineral extractive operation is susceptible of use and has value only in the place where the resources are found, and once the minerals are extracted it cannot again be used for that purpose. "Quarry property is generally a one-use property. The rock must be quarried at the site where it exists, or not at all. An absolute prohibition, therefore, practically amounts to a taking of the property since it denies the owner the right to engage in the only business for which the land is fitted."

Hansen, 12 Cal.4th at 553-54 (and cases cited therein).

Similarly, E&B's vested oil and gas rights are uniquely situated in the City, and the proposed ordinance seeks to terminate the extraction of those resources in the entire City, without the ability to extract them elsewhere. See *Los Angeles v. Gage*, 127 Cal.App.2d 442 (1954). Under the diminishing asset doctrine, E&B is entitled to produce oil and gas resources under its vested rights until the resource is exhausted or otherwise uneconomical to produce -- the continued production of oil and gas resources is the expanded use and is protected under *Hansen.*

6. The Proposed Ordinance is Preempted by State and Federal Law

The California Constitution states: "A county or city may make and enforce within its limits all local, police, sanitary, and other ordinances and regulations not in conflict with general laws." Cal. Const., Art. XI, Sec. 7. Local laws conflict with general law if the local laws duplicate, contradict or enter an area fully occupied by general law. *Morehart v. County of Santa Barbara*, 7 Cal.4th 725 (1994). The court in *Morehart states:*

> The general principles governing state statutory preemption of local land use regulation are well settled. "The Legislature has specified certain minimum standards for local zoning regulations (Gov. Code, § 65850 et seq.)" even though it also "has carefully expressed its intent to retain the maximum degree of local

> control (see, e.g., *id.*, § 65800, 65802)." (*IT Corp. v. Solano County Bd. of Supervisors* (1991) 1 Cal.4th 81, 89 [2 Cal.Rptr.2d 513, 820 P.2d 1023].) "A county or city may make and enforce within its limits all local, police, sanitary, and other ordinances and regulations *not in conflict with general laws.*" (Cal. Const., art. XI, § 7, italics added.) "'Local legislation in conflict with general law is void. Conflicts exist if the ordinance duplicates [citations], contradicts [citation], or enters an area fully occupied by general law, either expressly or by legislative implication [citations].'" (*People* ex rel. *Deukmejian v. County of Mendocino* (1986) 36 Cal.3d 476, 484 [204 Cal.Rptr. 897, 683 P.2d 1150], quoting *Lancaster v. Municipal Court* (1972) 6 Cal.3d 805, 807-808 [100 Cal.Rptr. 609, 494 P.2d 681]; accord, *Sherwin-Williams Co. v. City of Los Angeles* (1993) 4 Cal.4th 893, 897 [16 Cal.Rptr.2d 215, 844 P.2d 534].)

Morehart, 7 Cal.4th at 747; see also California Attorney General's opinion recognizing preemptive effect of State oil and gas laws, 59 Ops. Cal. Atty. Gen. 461,462 (1976).

Local regulations may also be preempted based on federal law under the Supremacy Clause of the U.S. Constitution. U.S. Const., Art. VI, cl. 2; see also *Ting v. AT&T*, 319 F.3d 1126, 1135 (9th Cir. 2003).

The City's proposed ordinance conflicts with California law regarding the production of oil and gas, including drilling, operations, abandonment and maintenance. The authority to regulate all aspects of oil and gas production, including downhole activities, rests with CalGEM. Cal. Pub. Res. Code §3106(b). The State's oil and gas laws read: "To best meet oil and gas needs in this state, the supervisor shall administer this division so as to encourage the wise development of oil and gas resources." Cal. Pub. Res. Code § 3106(d).

The State laws and associated regulations reflect an intent to occupy the entire area: Cal. Pub. Res. Code §§ 3000-3112 (General Provisions and Administration); Cal. Pub. Res. Code §§ 3130-3132 (Underground Injection Control), Pub. Res. Code §§ 3150-3161 (Well Stimulation); Cal. Publ. Res. Code §§ 3180-3187 (Natural Gas Storage Wells), Cal. Pub. Res. Code §§ 3200-3238 (Regulation of Operations); Cal. Pub. Res. Code §§ 3240-3241 (Abandoned Wells); Cal. Pub. Res. Code §§ 3250-3258 (Hazardous Wells); Cal. Pub. Res. Code §§ 3260-3263 (Acute Orphan Wells); Cal. Pub. Res. Code §§ 3270-3270.6 (Regulation of Production Facilities); Cal. Pub. Res. Code §§3275-3277 (Interstate Cooperation in Oil and Gas Conservation); Cal. Pub. Res. Code §§ 3300-3314 (Unreasonable Waste of Gas); Cal. Pub. Res. Code §§ 3315-3347 (Subsidence); Cal. Publ. Res. Code §§ 3350-3359 (Appeals and Review); Cal. Pub. Res. Code §§ 3400-3433 (Assessment and Collection of Charges); Cal. Pub. Res. Code §§ 3450-3451 (Recommendation of Maximum Efficient Rates of Production); Cal. Pub. Res. Code §§ 3780-3787 (Oil Sumps). The regulations include more detailed requirements for onshore wells (14 Cal. Code Reg. §§1712-1724.10), environmental protections for production facilities, tanks, pipelines (14 Cal. Code Reg. §§ 1750-1779.1), and expressly address well stimulation and seismic activity (14 Cal. Code Reg. §§ 1780-1789).

7. **The City's Proposed Ordinance Triggers Other Constitutional Violations (Due Process, Equal Protection, Contractual Relations)/Section 1983**

a. Equal Protection and Due Process

The U.S. and California Constitution's guarantee equal protection of the laws and adequate due process. These rights also apply in the land use context. Cal. Const., Art. 1, § 7(a); U.S. Const. amend V, XIV; *College Area Renters & Landlord Ass'n v. City of San Diego*, 43 Cal.App.4th 677, 686 (1996). Substantive due process addresses improper governmental interference with property rights and irrational actions by government decision-makers. *Lingle v. Chevron U.S.A. Inc.*, 544 U.S. 528, 541 (2005); *Arnel Development Co. v. City of Costa Mesa*, 126 Cal.App.3d 330, 337 (1981).

In the City's rush to adopt an amortization ordinance, the City has not followed the necessary procedures to demonstrate that oil and gas production in the City results in any environmental, health, or safety hazards. The City has failed to prepare any amortization study to support its purported 20-year amortization period, the proposed ordinance would prohibit maintenance to operate the wells, further curtailing operations, and it is recommending action by the City Council without completing the CEQA process. Furthermore, certain other oil and gas uses in the City are exempt, without sufficient explanation for those exemptions.

b. Impairment of Contractual Relations

Both the U.S. and California Constitutions prohibit the enactment of laws effecting a "substantial impairment" of contracts, which applies to public contracts as well as contracts between private parties. *Alameda County Sheriff's Assn. v. Alameda County Employees' Retirement Assn.*, 9 Cal.5th 1032, 1074 (2020). E&B has contracts with various private parties, which impose obligations on E&B that continue beyond the date the amortization period expires. The proposed ordinance will impair these contracts by forcing E&B to terminate its operations on or well before the 20-year deadline, which will undermine E&B's reasonable expectations under the contracts.

c. The City's Liability for Damages Under the Civil Rights Act

The federal Civil Rights Act, 42 U.S.C. § 1983 ("Section 1983"), provides a cause of action for damages based on claims arising from violations of federal rights. *Sveen v. Melin*, 138 U.S. 1815, 1822 (2018). As discussed at length herein, the proposed Ordinance will significantly impair E&B's constitutional rights, including its right to just compensation, due process rights, and equal protection rights. Accordingly, if the City adopts the proposed ordinance, the City will place itself at significant risk of liability under Section 1983, including for payment of damages suffered as a result of unreasonably phasing out oil and gas production in the City.

8. The City's CEQA Document is Out for Public Comment and City Cannot Make CEQA Findings

The City issued a notice that the Mitigated Negative Declaration is available for public comment and review, with the 30-day comment period closing on October 17, 2022. Until that process is complete, the City Planning Commission would not be able to make the CEQA findings set forth in the recommended action in the staff report. (Staff Report, p. F-6.)

9. The Proposed Ordinance Illegally Seeks to Eliminate the Dominant Estate of Oil and Gas Rights Across Entire City

The City's proposed ordinance seeks to eliminate all oil and gas production in the entire City. However, oil and gas rights function as a dominant estate, and this dominant estate allows the mineral rights holder to use the surface as reasonably required to access the minerals. *Vaquero Energy, Inc. v. County of Kern*, 42 Cal. App. 5th 312, 319-320 (2019); *Bourdieu v. Seaboard Oil Corp.*, 38 Cal. App. 2d 11, 16-17 (1940); *Wall v. Shell Oil Co.*, 209 Cal.App.2d 504, 511–514 (1962). The City fails to acknowledge and ignores this dominant estate in presenting the proposed ordinance, and provides no basis, much less a legitimate basis, for this action. The proposed ordinance would prevent any mineral rights holder from exercising the dominant estate protected by law. Separate and apart from the fact that the proposed ordinance would constitute a taking of this dominant estate and associated oil and gas rights, the City cannot as a matter of law eliminate the dominant estate from each and every parcel in the entire City.

10. Constitutes of Breach of Contracts between Oil and Gas Operators and City

E&B has several leases with the City for its oil and gas operations, and this proposed ordinance may serve to effect a breach of those leases.

For all of these reasons, we urge the City to reject the proposed ordinance and to reconsider its approach to oil and gas operations in the City.

Sincerely,

[ORIGINAL SIGNED]

Nicki Carlsen

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