CARB's Oil and Gas Methane Regulation
2019 Annual LDAR Summary

November 2021 (Revised January 2022)

California Air Resources Board

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A. Key Findings

- During the second year of implementation of CARB's Greenhouse Gas Emission Standards for Crude Oil and Natural Gas Facilities[1] (Oil and Gas Methane Regulation), over 7,000 leaks were identified and repaired during quarterly leak detection and repair (LDAR) surveys of ~2.3 million unique components.
- The ratio of leaks to unique components surveyed was 0.31%.
- The natural gas transmission sector had the largest ratio of leaks to components surveyed (0.69%), but the smallest number of components surveyed. The remaining three sectors (crude oil production, natural gas production, and natural gas storage) all had similar ratios of leaks to components surveyed (~0.30%).
- Approximately 20% of the leaks at or above the regulatory threshold of 10,000 ppmv accounted for 50% of the emissions.
- Total emission reductions from LDAR surveys in 2019 were estimated to be ~3,000 metric tons methane, or ~76,000 metric tons CO_2e.[2]
- LDAR surveys in 2019 resulted in a 12% reduction in emissions from components subject to LDAR in the regulation.

Table 1: Comparison of 2019 LDAR to Previous Years

	2018	2019
Total Count of Components in LDAR Program	1,970,710	2,289,040
Number of Leaks	11,359	7,208
Number of Leaks per Component Count in LDAR Program (%)		
Overall	0.58%	0.31%
Crude Oil Production Sector	0.36%	0.30%
Natural Gas Production Sector	0.68%	0.29%
Natural Gas Storage Sector	0.73%	0.30%
Natural Gas Transmission Sector	2.08%	0.69%
% of Leaks that Accounted for 50% of Emissions	20%	20%
Total Emission Reductions (metric tons methane)	5,400	3,000
% Emission Reductions	29%	12%

B. Background

As an early action measure to achieve the emission reductions required by the California Global Warming Solutions Act (AB 32), CARB adopted the Oil and Gas Methane Regulation to reduce methane emissions from oil and gas production, processing, storage, and transmission

[1] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4. Subarticle 13: Greenhouse Gas Emission Standards for Crude Oil and Natural Gas Facilities.

[2] CO_2e was calculated throughout the report using the 100-year global warming potential (GWP) of methane of 25.

compressor stations. CARB's Oil and Gas Methane Regulation was adopted by the Board on March 23, 2017 and went into effect on January 1, 2018. Section 95669 requires owners/operators of oil and natural gas facilities[3] to conduct quarterly LDAR surveys to monitor components for leaks and repair detected leaks within a specified time frame. Quarterly LDAR inspections began on January 1, 2018, and operators are required to submit annual LDAR reports to CARB by July 1 of each calendar year. The following information must be included in operators' annual LDAR reports:

1. Total number of components inspected
2. Total number of leaks identified per leak threshold category (10,000 to 49,999 ppmv, and 50,000 ppmv or greater)[4]
3. For each leak:
    a. Inspection date
    b. US EPA Method 21 instrument used
    c. US EPA Method 21 instrument calibration date
    d. Component type
    e. Equipment ID for the equipment the leaking component is on, if applicable
    f. Initial leak concentration
    g. Repair date
    h. Concentration after repair

This Annual LDAR Summary is based on annual reports CARB received from 94 operators for LDAR inspections at 380 facilities during 2019. In 2018, 69 operators submitted annual reports for inspections at 309 facilities. The number of annual reports likely increased due to improved operator compliance with the regulation during the second year of implementation. A comparison of 2018 and 2019 LDAR data is included in section D.

The LDAR requirements in CARB's Oil and Gas Methane Regulation do not apply to all components in California; there are two key exemptions. First, components that are subject to local air district LDAR requirements that were in place prior to January 1, 2018 are exempt from LDAR requirements in CARB's Oil and Gas Methane Regulation because the regulation was intended to cover components that were not already subject to district LDAR requirements.[5] Second, components handling crude oil with an API gravity less than 20 are not subject to LDAR requirements due to their very low emissions levels relative to other components found in gas

[3] Including oil and gas production, processing, and storage; natural gas gathering and boosting stations; natural gas underground storage; and natural gas transmission compressor stations.
[4] Beginning January 1, 2020, operators were also required to report leaks ranging from 1,000 to 9,999 ppmv.
[5] Oil and Gas Methane Regulation, Section 95669(b)(1).

or other liquid service (less than 1% of all emissions from leaking components in the state).[6,7,8,9] Figure 1 shows the fraction of oil and gas components in California that are subject to CARB's regulation, are subject to local air district rules,[10] or handle heavy oil and are exempt from LDAR requirements.[11]

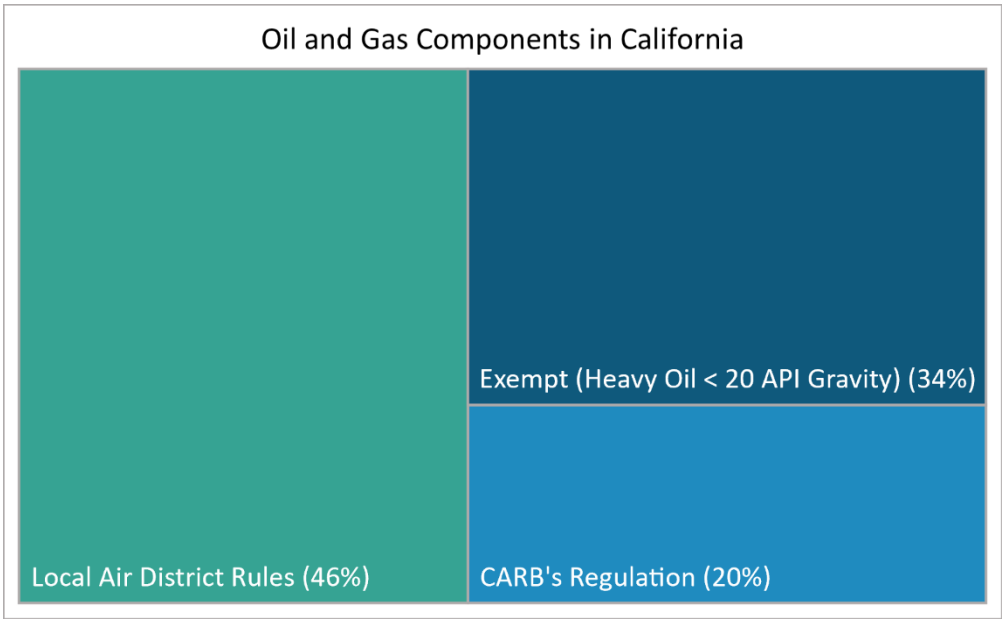

Figure 1: Breakdown of oil and gas components in California. Size of box corresponds to the percent of components in each category (shown in parentheses) based on data from CARB's 2007 oil and gas industry survey and the Oil and Gas Methane Regulation rulemaking.[12,13]

C. Summary of LDAR Data

During 2019 LDAR surveys, 2,289,040 unique components were surveyed[14] and 7,208 leaks were identified as greater than or equal to 10,000 ppmv (meaning that the ratio of leaks to

[6] Oil and Gas Methane Regulation, Section 95669(b)(2).
[7] ARB. (2013). Oil and Gas Survey. ARB 2007 Oil and Gas Industry Survey Results, Final Report, revised in October 2013.
[8] CAPCOA. (1999). California Implementation Guidelines for Estimating Mass Emissions of Fugitive Hydrocarbon Leaks at Petroleum Facilities.
[9] 15-Day Notice Attachment 2. https://ww3.arb.ca.gov/regact/2016/oilandgas2016/oilgasatt2.pdf.
[10] There are eight local air districts with LDAR requirements for oil and gas facilities, including Bay Area Air Quality Management District (AQMD), Monterey Bay Air Resources District (ARD), San Joaquin Valley Air Pollution Control District (APCD), San Luis Obispo County APCD, Santa Barbara County APCD, South Coast AQMD, Ventura County APCD, and Yolo-Solano AQMD.
[11] Heavy oil is defined differently in different district rules, e.g., by API gravity, by flash point, by vapor pressure, or by evaporation percentage. For the purposes of Figure 1, heavy oil was defined as < 20 API gravity.
[12] See footnote 7.
[13] See footnote 9.
[14] Component surveys were repeated quarterly for a total of ~9 million component inspections.

components surveyed was 0.31%). Of the leaks found as part of the inspections, 7,172 were repaired or replaced, 32 were critical components[15] and were repaired at the next scheduled shutdown or within 12 months, whichever was sooner, and 4 were delays of repair at the time of reporting and were repaired or replaced within 30 calendar days from the allowed repair time period or by the anticipated repair date stated in the operator's approved delay of repair request. Delays of repairs are requested by operators who need to order specific parts or equipment to repair the leaking component. CARB staff tracks the delay of repair requests to confirm that repairs are completed according to the allowed timeline.[16]

CARB staff reviewed the data in the 2019 annual reports and found no widespread issues with operators' reported data. Issues encountered were all associated with data entry and include conflicting inspection dates, conflicting repair dates, incorrect number of components inspected, incorrect number of leaks found, and incorrect repaired leak concentrations. All discrepancies were corrected by CARB staff after following up with operators. During 2019, 0.61% of the reported leaks had potential errors identified that required CARB staff to follow up with operators and make necessary corrections. Of the facilities that reported LDAR data, 3.2% had discrepancies between the number of leaks recorded in the annual LDAR reports' two reporting tables, and 2.6% of all reported quarterly inspections listed incorrect inspection dates (i.e., dates were not in 2019). The validity of the data presented in this report is dependent on the accuracy of the data reported by operators. CARB acknowledges that there are potential limitations with self-reported data; however, CARB staff conducted rigorous quality control checks to ensure the highest level of data integrity possible. There were fewer issues identified with 2019 LDAR reporting data compared to 2018, demonstrating that as operators gain experience with the regulation, their annual reports require less follow-up by CARB staff.

Table 2 shows the LDAR survey leak distribution for 2019 broken down by oil and gas sector. The allowed leak threshold for 2018 and 2019 was 10,000 ppmv; on January 1, 2020, it decreased to 1,000 ppmv. Natural gas transmission had the largest ratio of leaks to unique components surveyed (0.69%), but the smallest number of components surveyed. The remaining three sectors (crude oil production, natural gas production, and natural gas storage) all had similar ratios of leaks to components surveyed (~0.30%), and crude oil production had the largest number of components surveyed.[17] Figure 2 shows the number of leaks identified in 2019 by component type; connectors and valves had the most leaks of the component types.

[15] A critical component would require the shutdown of a critical process unit if that component was shutdown.
[16] The 36 critical component and delay of repair leaks were included in this report in Tables 1 and 2 and Figures 2 and 3, but not in estimates of emission reductions because those calculations require a concentration after repair.
[17] In general, district LDAR rules cover crude oil production facilities; however, the Oil and Gas Methane Regulation addressed some components that are exempt from district rules, resulting in the large number of components in the crude oil production sector as shown in Table 2.

Table 2: Components Found Leaking by Sector in 2019

Sector	Total Count of Components in LDAR Program[18]	Number of Leaks in Each Category[19]		Number of Leaks per Component Count in LDAR Program (%)
		10,000 to 49,999 ppmv	50,000 ppmv or greater	
Crude Oil Production	1,422,282	3,482 (0.24%)	734 (0.05%)	0.30%
Natural Gas Production	347,614	985 (0.28%)	35 (0.01%)	0.29%
Natural Gas Storage	409,719	781 (0.19%)	432 (0.11%)	0.30%
Natural Gas Transmission	109,425	490 (0.45%)	269 (0.25%)	0.69%
Total	2,289,040	5,738 (0.25%)	1,470 (0.06%)	0.31%

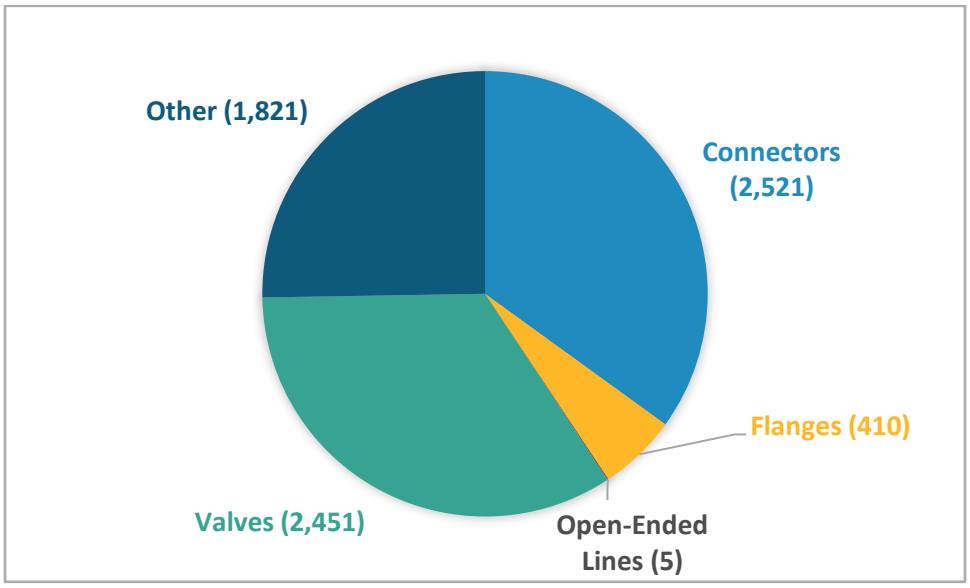

Figure 2: Number of leaks identified in 2019 by component type. The "other" component category includes gas regulators, pressure gauges, pressure relief devices, flow and pressure meter fittings, pneumatic devices, compressor vents, temperature controllers, stuffing boxes, and inactive flare pilots.

CARB staff estimated emissions from the reported leaks using correlation equations developed by Sage.[20] Estimated methane leak rate statistics by component type are shown in Table 3. On

[18] These counts include the physical number of components that were surveyed four times throughout the year.
[19] A component could have been found to be leaking during a quarterly inspection and been repaired or replaced within the required time period, but may have been measured as leaking again during a subsequent quarterly inspection, resulting in one component accounting for more than one leak.
[20] Air Resources Board IFB No. 13-414: Enhanced Inspection & Maintenance for GHG & VOCs at Upstream Facilities, Sage ATC Environmental Consulting LLC, revised November 2019.

average, open-ended lines had the highest leak rates, although they accounted for only five leaks total. The mean leak rate from all components was 0.049 kg CH_4/hr.

Table 3: Methane Leak Rate Statistics by Component Type[21]

	All Components	Connector	Flange	Open-Ended Line	Valve	Other[22]
Min (kg CH_4/hr)	0.008	0.008	0.008	0.060	0.021	0.029
Max (kg CH_4/hr)	0.877	0.178	0.111	0.165	0.877	0.516
Mean (kg CH_4/hr)	0.049	0.018	0.018	0.140	0.062	0.082
Median (kg CH_4/hr)	0.034	0.014	0.015	0.160	0.051	0.070

Figure 3 shows the cumulative leak emission distribution from 2019, which demonstrates that ~20% of leaks accounted for 50% of estimated emissions from leaking components. This shows that a relatively small number of sources contributed to a significant portion of the emissions, as has been demonstrated in previous studies of oil and gas facilities.[23,24]

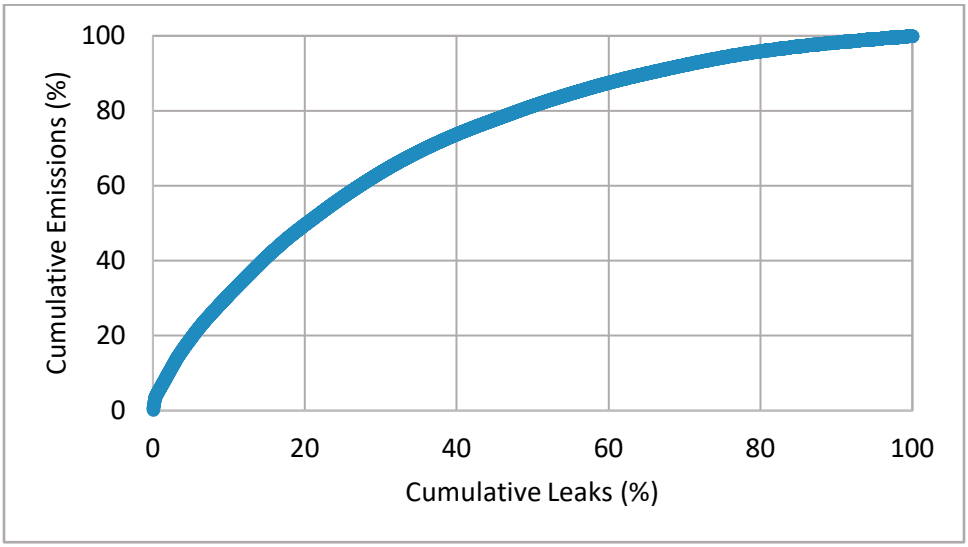

Figure 3: Fraction of cumulative emissions versus cumulative leaks based on LDAR data for 2019.

[21] Leak rates were converted from total hydrocarbons assuming a methane composition of 89.2% based on data from the Sage study (see footnote 20).
[22] The max leak rate of 0.516 kg CH_4/hr was on a thermal oxidizer.
[23] Allen, D. (2016). Emissions from oil and gas operations in the United States and their air quality implications. *Journal of the Air & Waste Management Association*, 66:6, 549-575. DOI: 10.1080/10962247.2016.1171263.
[24] Brandt et al. 2016. Methane Leaks from Natural Gas Systems Follow Extreme Distributions. *Environmental Science & Technology*, 50:22, 12512-12520. DOI: 10.1021/acs.est.6b04303.

Emission reductions were estimated by assuming that a leak would have continued unabated for a year without the LDAR program. Total emission reductions from the 2019 LDAR surveys were estimated to be ~3,000 metric tons methane, or ~76,000 metric tons CO_2e.[25] CARB staff also estimated baseline 2019 emissions from all components subject to LDAR in the regulation in order to evaluate the percent emission reductions from 2019 LDAR surveys. Operators are not required to report concentration data for components measured to be below the leak threshold (10,000 ppmv); therefore, emissions from these "non-leaking" components were estimated by assuming a leak rate equal to the average post-repair leak rate of all leaking components. Similar to emission reductions, baseline emissions from leaks were estimated by assuming that leaks would have persisted for a year without the LDAR program. The combined total baseline emissions from leaking and "non-leaking" components subject to quarterly LDAR surveys for CARB's Oil and Gas Methane Regulation during 2019 was estimated to be ~25,000 metric tons methane,[26,27] or ~610,000 metric tons CO_2e.[28] Based on those calculations, 2019 LDAR surveys resulted in a 12% reduction in emissions from components subject to LDAR in the regulation.

Leak data broken down by local air district and owner/operator are shown in Appendix A. Figures A-1 and A-3 show emission reductions from each sector (crude oil production, natural gas production, natural gas transmission, and natural gas storage), and Figures A-2 and A-4 show the ratios of leaks to components surveyed for each sector.[29] San Joaquin Valley Air Pollution Control District (APCD) had the highest emission reductions, with the majority coming from the crude oil production sector (Figure A-1). For all the local air districts with natural gas transmission facilities, the transmission sector had the highest ratios of leaks to components surveyed of the four sectors (Figure A-2). The owner/operator with the highest emission reductions was Aera, followed by California Resources Corporation and Southern California Gas Company (SoCalGas) (Figure A-3). The owners/operators with the highest ratios of leaks to components surveyed were R&R Resources, Western Metals Corporation, and Longbow; no clear trends were observed across sectors (Figure A-4).

[25] ~220,000 metric tons CO_2e using the 20-year GWP of methane of 72.
[26] Converted from total hydrocarbons assuming a methane composition of 89.2% based on data from the Sage study (see footnote 20).
[27] Leaking and "non-leaking" components accounted for ~3,100 and ~21,400 metric tons methane, respectively.
[28] ~1,800,000 metric tons CO_2e using the 20-year GWP of methane of 72.
[29] The ratio metric in this report should not be compared to the "% of total inspected" metric in Tables 1 and 3 of CARB's Oil and Gas Methane Regulation. Tables 1 and 3 pertain to single inspections of a group of components during district or CARB inspections; the ratios in this report represent four inspections of a group of components during operator inspections. The ratio metric also should not be compared to the loss rate used in the Oil Production Greenhouse gas Emissions Estimator (OPGEE).

D. Comparison to 2018 Data and Conclusions

During 2019 LDAR surveys, operators inspected more unique components (2,289,040 compared to 1,970,710 in 2018) and identified fewer leaks as greater than or equal to 10,000 ppmv (7,208 compared to 11,359 in 2018). The overall ratio of leaks to unique components surveyed decreased from 0.58% in 2018 to 0.31% in 2019, and the ratios by sector also decreased across all sectors. Natural gas transmission remained the sector with the highest leak ratio, but the ratio for the sector decreased from 2.08% in 2018 to 0.69% in 2019. The crude oil production sector leak ratio decreased from 0.36% in 2019 to 0.30% in 2018, natural gas production decreased from 0.68% to 0.29%, and natural gas storage decreased from 0.73% to 0.30%. In both 2018 and 2019, the crude oil production sector had the largest number of components surveyed and the natural gas transmission sector had the smallest number.

Leak counts by component type were similar for 2018 and 2019 with connectors and valves having the most leaks of the component types for both years, followed by the other category. In both 2018 and 2019, open-ended lines had the highest leak rates on average, although they accounted for the smallest number of leaks. The mean leak rate from all components decreased from 0.056 kg CH_4/hr in 2018 to 0.049 kg CH_4/hr in 2019. The cumulative leak distribution in 2019 was similar to 2018, with ~20% of leaks accounting for 50% of total emissions.

Emission reductions were smaller in 2019 than 2018, with reductions of ~3,000 metric tons methane in 2019 compared to ~5,400 metric tons methane in 2018. The decrease in emission reductions in 2019 was due to the smaller number of leaks identified compared to 2018. Conversely, baseline emissions from components subject to quarterly LDAR surveys were larger in 2019 relative to 2018 (~25,000 metric tons methane in 2019 compared to ~19,000 metric tons methane in 2018). This increase is due to increases in both the total number of components surveyed and the average post-repair leak rate. LDAR surveys in 2019 resulted in a 12% reduction in emissions from components subject to LDAR in the regulation compared to 29% in 2018; the decline from 2018 to 2019 was caused by the decrease in emission reductions as well as the increase in baseline emissions.

The decrease in the total number of leaks identified from 2018 to 2019, even though more components were inspected, suggests that implementation of an LDAR program can potentially reduce the number of leaks over time and not just ensure they do not increase above a steady state leak count, but more years of data will be needed to confirm that trend. The leak count may increase in 2020 due to the leak threshold decreasing from 10,000 ppmv to 1,000 ppmv. Furthermore, even with a reduced number of total leaks, frequent LDAR surveys remain necessary to identify and mitigate emissions from the relatively small number of larger leaks that have an outsized impact on overall emissions from leaking components.

Appendix A: LDAR Data by Local Air District and Owner/Operator

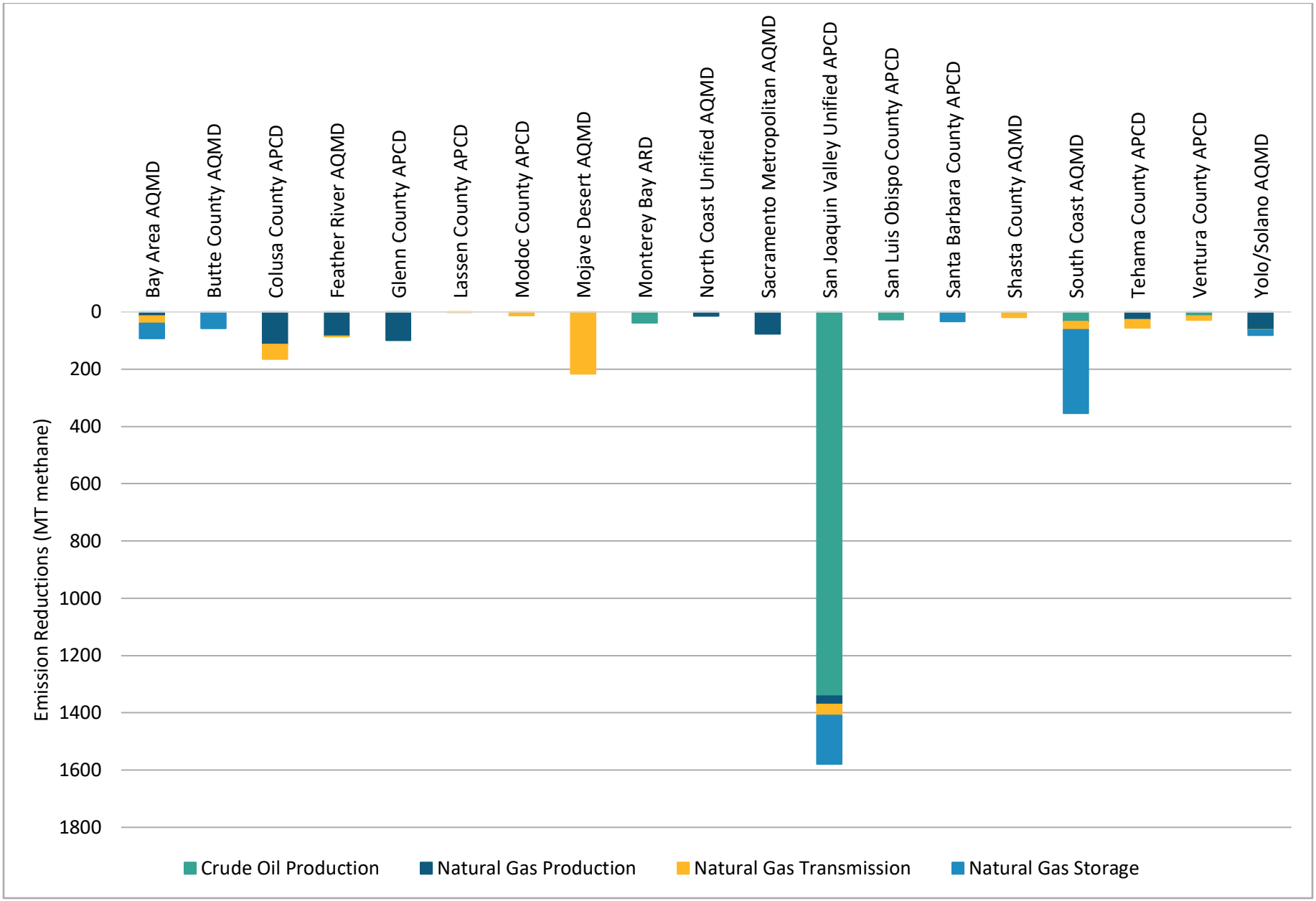

Figure A-1: Emission reductions from each sector by local air district during 2019.

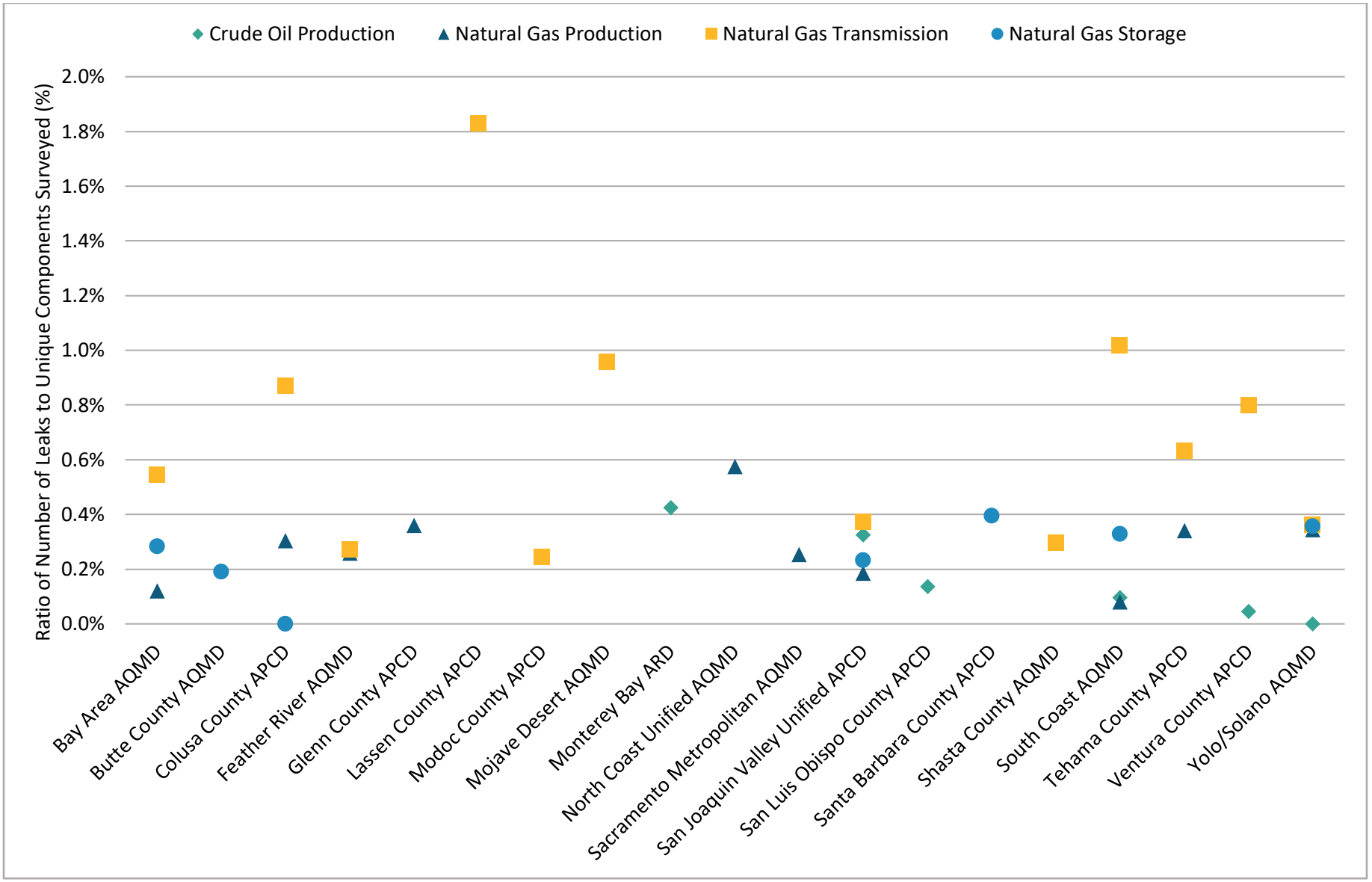

Figure A-2: Ratios of numbers of leaks to numbers of unique components surveyed for each sector by local air district during 2019. Note there are overlapping values: Feather River AQMD had ratios of 0.26% and 0.27% for natural gas production and natural gas transmission, respectively, and Yolo/Solano AQMD had ratios of 0.34%, 0.36%, and 0.36% for natural gas production, natural gas transmission, and natural gas storage, respectively.

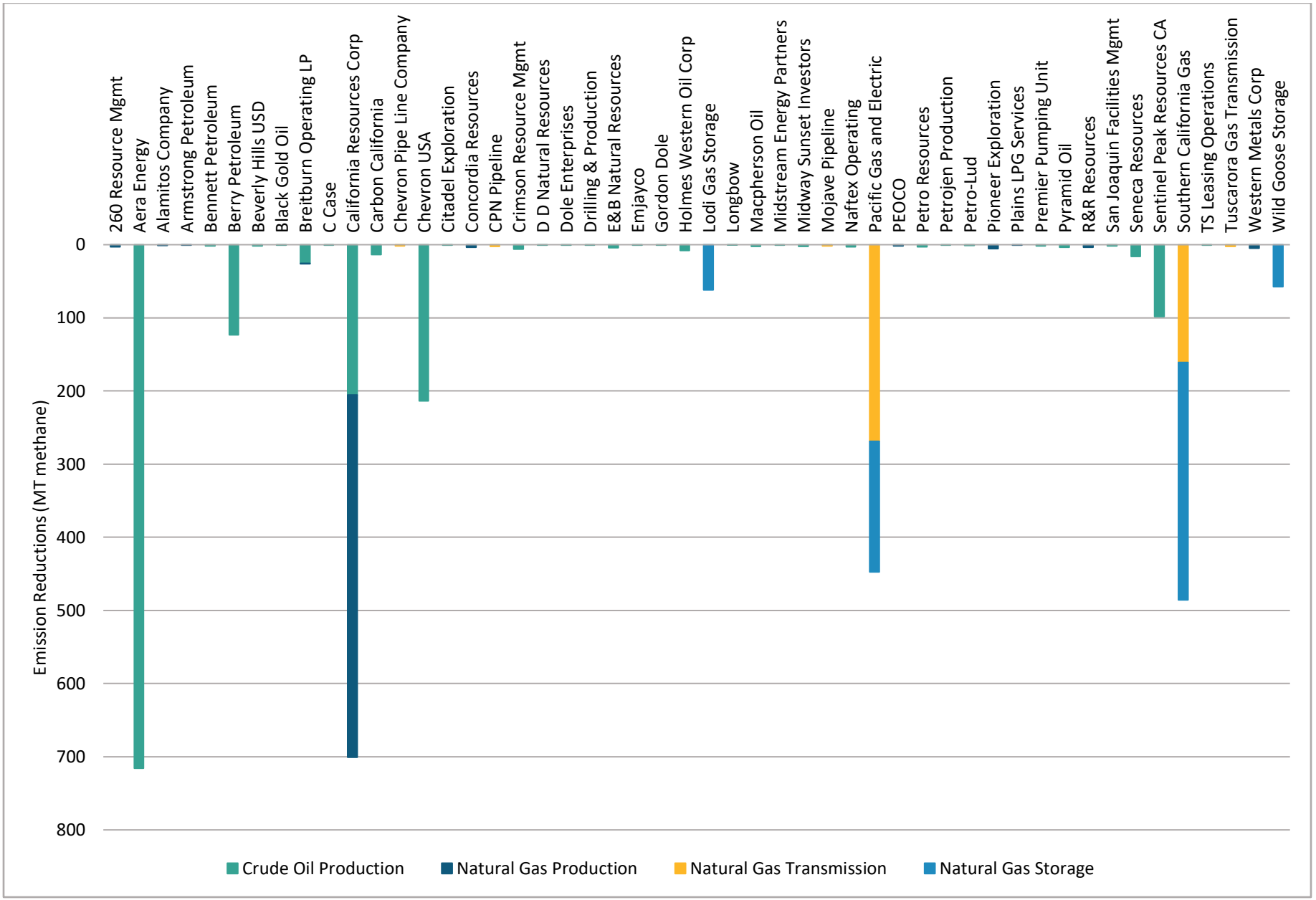

Figure A-3: Emission reductions from each sector by owner/operator during 2019. Of the 94 operators who conducted quarterly LDAR surveys, 44 did not measure any leaks at or above 10,000 ppmv and are therefore not shown here.

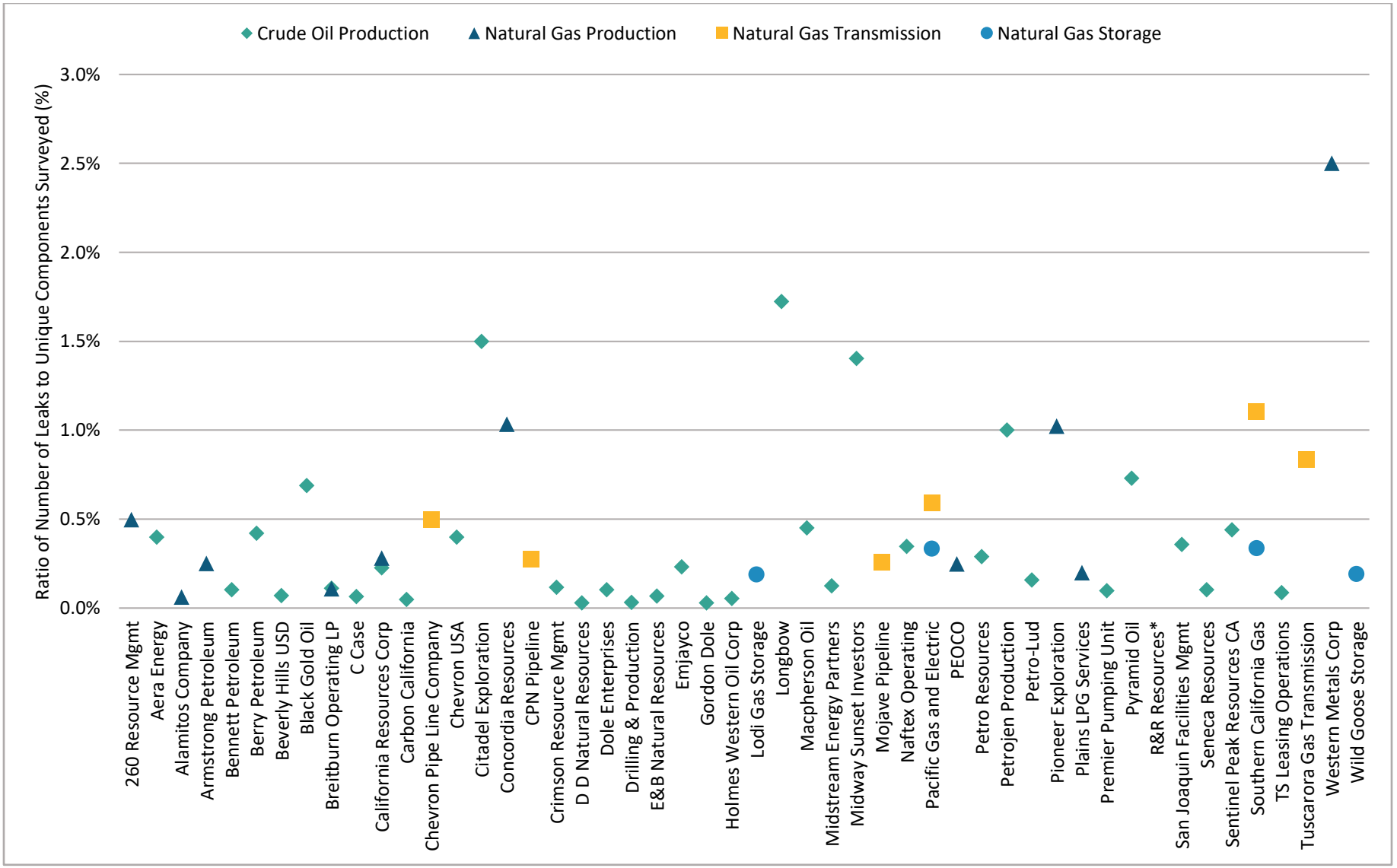

Figure A-4: Ratios of numbers of leaks to numbers of unique components surveyed for each sector by owner/operator during 2019. Of the 94 operators who conducted quarterly LDAR surveys, 44 did not measure any leaks at or above 10,000 ppmv and are therefore not shown here. Note there are overlapping values: Breitburn Operating LP had ratios of 0.11% for both crude oil production and natural gas production. *R&R Resources had a ratio for natural gas production of 16%, but the y-axis in this figure was limited to 0-3% to better illustrate the variation between the vast majority of operators.