

Long-Term Viability of Underground Natural Gas Storage in California

An Independent Review of Scientific and
Technical Information

Chapter 1, Section 1.7
Summary and Conclusions

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1.7 RISK-RELATED CHARACTERISTICS OF UGS SITES IN CALIFORNIA

1.7.1 Integrative Table

In the previous six sections of this report, we have reviewed the state of UGS in California from the perspective of the risk posed by UGS to health, safety, the environment, and UGS infrastructure itself, and we presented discussion of managing and mitigating these risks. To summarize the detailed discussion and analysis of this chapter, we provide here a summary as shown in Table 1.7-1 that allows readers to see at a glance some of the most salient characteristics of UGS sites in California related to the various aspects of UGS risk.

The rows in Table 1.7-1 comprise descriptive attributes, specific hazard categories, health- and exposure-related aspects, and GHG emission categories. The columns of the table list the 13 California UGS facilities organized by ownership, with the independent facilities listed first, the northern California utility-owned facilities listed second, and the southern California facilities listed third.

Where appropriate, we made a judgment about the qualitative relative level of risk associated with each value or descriptor in the table, as shown by the shading of the color. Specifically, darker shades generally correspond to larger expected hazard, while lighter shades correspond to less expected hazard from that attribute. We emphasize that this qualitative assessment is independent of (i.e., does not take into account) any and all risk mitigation actions that may have been implemented at the sites. In addition, the storage capacity attribute can be seen as both a risk-related characteristic—more mass available to leak in a blowout—or a benefit—more capacity to store gas. But we assign larger-capacity facilities darker shadings because the table is on risk-related characteristics only, not on benefits. Furthermore, the qualitative comparative assessments made possible by the information in Table 1.7-1 in no way take the place of the QRA recommended previously in Section 1.6 for each facility. Instead, Table 1.7-1 is useful for comparing UGS sites qualitatively across all facilities in California. Finally, we note that the Montebello facility was officially closed December 31, 2016, following extensive surface leakage of natural gas over decades; it is included in Table 1.7-1 because it apparently operated for some periods during our 10-year study period January 1, 2006 to December 31, 2015.

1.7.2 Example Uses of Table

As an example of one particular risk scenario, an initiating event for a large-scale LOC event might be well integrity failure by corrosion or sand erosion of steel pipe or casing. Both of these are more likely to become problems for older and repurposed wells. Therefore, age of wells is a relevant attribute. From the UGS Characteristics section of the table, we note that the median spud date of wells active in 2015 for the Playa del Rey, La Goleta, and Aliso Canyon facilities are all from before the mid-1950's, and for Playa del Rey, the median spud date year is 1935.

Other initiating events that could rupture a well or flowline leading to significant LOC are landslides and earthquakes, especially those that may cause slip on faults intersected by wells. A glance at the table in the Failure Modes section shows that Aliso Canyon and Honor Rancho have relatively high landslide hazard, while Aliso Canyon, Honor Rancho, La Goleta, and Montebello all have relatively high seismic hazard. Wildfire is another hazard that could impact surface infrastructure and its ability to contain high-pressure gas. Table 1.7-1 also shows that Aliso Canyon, Honor Rancho, and Playa del Rey all have very high wildfire hazard.

Regarding the likelihood side of this high-level comparative risk example, we note that Aliso Canyon, Montebello, and Playa del Rey have a history of multiple recorded LOC incidents, while Honor Rancho has one recorded incident. The table also shows that McDonald Island has two recorded incidents of significant LOC, and there have been reports of recent surface gas leakage not yet included in publications.

Finally, as we turn now to consider potential consequences of large-scale LOC incidents, the Health and safety section of Table 1.7-1 shows very low populations surrounding most of the UGS facilities in California, with notable exceptions at Montebello, Playa del Rey, Aliso Canyon, Los Medanos, and Honor Rancho. The implication is that larger numbers of people could be impacted by LOC incidents from these five facilities relative to comparable releases from the other facilities.

What emerges from the above example of high-level qualitative comparative risk assessment of the UGS facilities in California is that Playa del Rey stands out as a facility with relatively higher risk to health and safety than the other facilities in California. Aliso Canyon, Honor Rancho, and La Goleta also present health and safety risk higher than other facilities, in part because of their location near large numbers of people. Los Medanos is also near significant population and has recorded LOC incidents, but its wildfire and landslide hazard are only moderate. We note again that Table 1.7-1 presents many qualitative attributes that in the near future can be further quantified based on the risk management plans that each facility is now required to develop according to DOGGR's emergency and draft regulations, along with the quantitative risk assessment (QRA) recommended in this report (see Section 1.6).

1.7.3 Conclusions for site-specific hazard and risk assessment

Finding: The hazards, vulnerabilities, and risk levels are generally different for facilities that store gas in former gas reservoirs versus former oil reservoirs, and also differ qualitatively among individual facilities based on their unique characteristics. Identification of such differences allows the high-level or preliminary assessment of which UGS sites in California may present higher risk to health, safety, and the environment than others, overall or for certain risk categories and scenarios. High-level identification of such risk-related differences can lead to more specialized and effective risk management and mitigation approaches for each setting.

Conclusion: Qualitative assessment of risk-related characteristics of California UGS facilities points to relatively larger potential risk in facilities that have older repurposed wells often in former oil reservoirs, are located in hazard zones for seismic or other natural disaster risks, may have a higher rate of LOC incidents, and are located near large population centers. (See Conclusion 1.25a in Executive Summary.)

Conclusion: Of the currently operating facilities, Playa del Rey stands out as a facility with risk-related characteristics with high concern for health and safety relative to the other facilities in California, followed by Aliso Canyon, Honor Rancho, La Goleta and Los Medanos. (See Conclusion 1.25b in Executive Summary.)

The qualitative risk-related information in Table 1.7-1, and in the near future more quantitative risk assessments of each facility, can be used by decision-makers to examine the tradeoffs between potential hazards and risks associated with facilities and their importance in meeting the demands of the natural gas supply. This can and should be done facility by facility: For example, the Aliso Canyon facility according to Table 1.7-1 is at relatively higher risk because of certain attributes and the nearby population, but it also has important benefits because of its large gas storage capacity. In contrast, Playa del Rey has record of LOC incidents, is near a large population center, features tsunami and wildfire threats, and has a relatively small gas storage capacity. While the high-level and qualitative comparative risk assessment described here provides important information for assessing long-term viability, it is only one-half of the equation. In particular, the assessment here only looks at the facility-specific risks of UGS without looking at the facility-specific benefits of UGS.

Recommendation: The State of California should conduct a comparative study of all UGS facilities to better understand the risk of individual facilities relative to others. This comparative study should be based on the risk management plans being developed for each facility and should be commissioned when such risk management plans have matured to the point that they comprise formal risk assessments and mitigation plans (e.g., in five years). The end product would be a table similar to Table 1, but the revised table would be based on quantitative rather than qualitative information. The quantitative risk-related information on each facility can then be used by decision makers to examine the tradeoffs between risks associated with individual facilities and their importance in meeting the demands of the natural gas supply. (See Recommendation 1.25 in Executive Summary.)

Table 1.7-1. Comparative risk-related characteristics for California UGS facilities (layout of this table is for size 11"x 17" paper). Darker shades generally correspond to larger values or larger expected hazard while lighter shades correspond to less expected hazard from that attribute.

Chapter 1

Facility ¹	Gill Ranch Gas	Kirby Hill Gas	Independents	Princeton Gas	Wild Goose Gas	Los Medanos Gas	Pacific Gas and Electric	Pleasant Creek Gas	Aliso Canyon	Honor Rancho	Southern California Gas	Playa del Rey	Lowest	Low	Medium	High	Highest
1.1 USE Characteristics	Merced	Fairfield	Lodi & Gait	Willows	Gridley	Concord	Stockton	Winters	Los Angeles	Santa Clara	La Goleta	Los Angeles	1,550 - 3,000	3,000 - <6,000	6,000 - <8,000	8,000 - 10,000	
Nearest incorporated city or cities	Merced	Fairfield	Lodi & Gait	Willows	Gridley	Concord	Stockton	Winters	Los Angeles	Santa Clara	La Goleta	Los Angeles					
County or counties (if a second county is listed, it only contains a portion of this connection line)	Merced	Fairfield	Lodi & Gait	Willows	Gridley	Concord	Stockton	Winters	Los Angeles	Santa Clara	La Goleta	Los Angeles					
Owner/operator	Gill Ranch LLC (75%), PG&E (25%)	Solino	Sacramento Rockpoint	AGI (through Photovoltaic Development)	Rockpoint	PG&E	PG&E	PG&E	SocalGas	SocalGas	SocalGas	SocalGas					
Average depth (range) of storage reservoir(s) (ft)	5,850 - 6,216	1,350 - 5,400	2,280 - 2,515	2,170	2,400 - 2,900	4,000	5,220	2,800	9,000	10,000	3,950	6,200	1,550 - 3,000	3,000 - <6,000	6,000 - <8,000	8,000 - 10,000	
Starting year	2010	2006	2001	2012	1998	1976	1962	1962	1973	1975	1942	1942	2005 - 2012	1985 - 2004	1965 - 1984	1942 - 1964	
Capacity (bcf)	0.0	5.0	17.0	0.0	20.3	17.4	82.0	2.3	82.0	23.0	21.5	2.6	2.3 - <3.0	3.0 - <10.0	10.0 - <30.0	30.0 - 82.0	
Average % capacity utilized annually, 2006 to 2015	3%	20%	12%	47%	50%	57%	45%	55%	69%	108%	56%	160%	35% - <50%	50% - <80%	80% - <10%	110% - 15%	
Median tubing pressure per pool (psig, % of initial)	2,828 (88%)	1,019 (89%)	846 (86%)	1,080 (100%)	1,251 (98%)	1,350 (79%)	1,850 (79%)	1,206 (95%)	2,280 (63%)	2,730 (61%)	1,676 (87%)	1,370 (50%)	63 - <130	1,300 - <1,700	1,700 - <2,100	2,100 - 2,730	
Average annual gas transfer per well per month gas was transferred from 2006 to 2015 (million scf)	150	69	511	78	866	255	75	22	197	244	232	13	13 - <20	20 - <100	100 - <500	500 - 866	
Wells connected to storage reservoir	12	18	17	8	17	21	81	7	111	38	17	34		7 - 9	10 - 25	25 - 74	75 - 111
Number of wells open in 2015	0	0	9	5	0	0	7	0	4	3	1	20	0	1 - 9	10 - 20		
Oldest (yrs)	5	40	72	61	16	41	78	66	75	59	85	84	5 - 24	25 - 49	50 - 74	75 - 85	
Median (yrs)	5	7	13	4	7	36	41	41	42	39	63	79	4 - 24	25 - 49	50 - 74	75 - 79	
Estimated number of public and domestic groundwater wells to 2015 ² (total)	0.1	0.1	9.2	0.9	0.0	0.5	0.1	1.7	0.0	0.0	0.4	0.0	0.0 - 1.0	1.0 - <3.0	3.0 - <6.0	6.0 - 9.2	
Depth of the base of fresh water (ft)	1.4	1.2	11.6	3.4	0.0	1.7	1.1	5.4	0.0	0.3	2.9	5.0				6.0 - 11.6	
Maximum storage pool depth	950	1,850	2,485	1,870	1,000	2,140	100	2,270	Not available	Not available	None	800	NA	100 - <1,000	1,000 - <2,000	2,000 - 2,485	
Above minimum storage pool depth	4,900	-300	-205	300	1,400	1,860	5,120	530	Not available	Not applicable	Not applicable	5,400	5,400 - >2,000	2,000 - >1,000	1,000 - >0	0 - 300	
Max. perf. depth of public, domestic, or irrigation well (ft)	510	195	693	400	Not available	320	290	870	No wells	145	1,270	No wells	NA	145 - <400	400 - <800	800 - 1,270	
% of max. fresh water	51%	11%	24%	21%	Not available	15%	29%	36%		Not calculable	infinite		11% - <25%	25% - <50%	50% - 75%	>75% - 250%	
% of public, domestic, and irrigation wells with BPH depth	100%	56%	47%	42%	0%	69%	56%	94%		75%	95%		NA and 100%	<100% - 80%	<80% - 60%	<60% - 42%	0%
CASGEM basin identification ³	High	Very Low	High	Medium	Medium	None	Medium	High	Medium	Medium	None	Medium	None	Very Low	Medium	High	

¹ Storage in facilities whose name includes "Gas" is in depleted gas reservoirs; otherwise storage is in depleted oil reservoirs

² "open" includes wells with DOGR status "Active" and "Idle", which are unplugged and have a wellhead

³ CASGEM = California Statewide Groundwater Elevation Monitoring

x - data not collected because Montebello is not operating as of 2017

Chapter 1

Facility ¹	Pacific Gas and Electric											Southern California Gas			Hazard highlighting ranges and categories (NA = not applicable or available)				
	Gill Ranch Gas	Kirby Hill Gas	Independents	Princeton Gas	Wild Goose Gas	Los Medanos Gas	McDonald Island Gas	Pleasant Creek Gas	Aliso Canyon	Honor Rancho	La Brea	Montebello	Playa del Rey	Lowest	Low	Medium	High	Highest	
1.2 Fallow modes and likelihoods and hazards (Wells and field lines)	0	VI	0	0	0	VI	0	VII	X	X	V	X	(0)	(V)	(VI)-(VIII)	(IX)-(X)			
bandwidth susceptibility	0	VII	0	0	0	III	0	V	X	X	VII	X	None	<130,000*	<130,000 - <15,000*	<15,000			
last fault rupture through or (*) within 500 m of field line(s) (yrs age)	None	<130,000	None	None	None	<130,000*	None	None	<15,000*	<130,000*	None	None	None						
Hazard of Quaternary fault shearing of wells) present	No	Yes	No	No	No	Maybe	No	No	Yes	Unlikely	No	No	No	Unlikely	Maybe	Yes			
Maximum 2% probability of exceeding 0.2-sec spectral acceleration in 50 years (g)	0.85	1.55	0.65	0.75	0.65	2.15	1.15	1.75	2.55	2.45	2.15	1.65		0.65 - <1.00	1.00 - <2.00	2.00 - 2.75			
Field line(s)	0.85	1.55	0.65	0.75	0.65	2.15	1.15	1.85	2.55	2.45	2.15	1.65							
Plant	0.85	1.55	0.65	0.75	0.65	2.15	1.15	1.85	2.55	2.45	2.15	1.65							
Connection line	1.45	1.55	1.25	0.95	0.65	2.15	1.25	1.85	2.75	2.45	2.15	1.55							
Maximum 2% probability of exceeding 1-sec spectral acceleration in 50 years (g)	0.45	0.55	0.35	0.45	0.45	0.85	0.75	0.85	1.45	1.15	1.05	0.95		0.35 - <0.50	0.50 - <1.00	1.00 - <1.50		1.50 - 1.55	
Field line(s)	0.45	0.55	0.35	0.45	0.45	0.85	0.75	0.85	1.45	1.15	1.05	0.95							
Plant	0.45	0.55	0.35	0.45	0.45	0.85	0.75	0.85	1.45	1.15	1.05	0.95							
Connection line	0.75	0.85	0.85	0.55	0.45	0.75	0.85	0.75	1.45	1.05	1.05	0.95		0.35 - <0.50	0.50 - <1.00	1.00 - 1.45			
Liquefaction hazard zone	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	No (unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	No		?	Yes			
Well(s) and field line(s)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	No (unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	No						
Connection line	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	No (unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	No						
Earthquake-induced landslide hazard zone	No (unmapped, but includes all)	?(unmapped, but includes all)	No (unmapped, but includes all)	No (unmapped, but includes all)	No (unmapped, but includes all)	?(unmapped, but includes all)	No (unmapped, but includes all)	No (unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	No						
Plant	No (unmapped, but includes all)	?(unmapped, but includes all)	No (unmapped, but includes all)	No (unmapped, but includes all)	No (unmapped, but includes all)	?(unmapped, but includes all)	No (unmapped, but includes all)	No (unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	No						
Connection line	No (unmapped, but includes all)	?(unmapped, but includes all)	No (unmapped, but includes all)	No (unmapped, but includes all)	No (unmapped, but includes all)	?(unmapped, but includes all)	No (unmapped, but includes all)	No (unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	?(unmapped, but includes all)	No						
Tsunami hazard	No	No	No	No	No	No	No	No	No	No	No	No	No						
Wells)	No	No	No	No	No	No	No	No	No	No	No	No	No						
Field line(s)	No	No	No	No	No	No	No	No	No	No	No	No	No						
Plant	No	No	No	No	No	No	No	No	No	No	No	No	No						
Wells) and field line(s)	No	No	No	No	No	No	No	No	No	No	No	No	No						
Plant	No	No	No	No	No	No	No	No	No	No	No	No	No						
Connection line	No	No	No	No	No	No	No	No	No	No	No	No	No						
Fires hazard severity zones (prevalent, non-prevalent, (medium, (Field lines) different)	Yes (unmapped, but includes all)	Moderate (unmapped, but includes all)	Moderate (unmapped, but includes all)	Not zoned (unmapped, but includes all)	Not zoned (unmapped, but includes all)	Moderate (unmapped, but includes all)	Moderate (unmapped, but includes all)	Moderate (unmapped, but includes all)	Very high (unmapped, but includes all)	Very high (unmapped, but includes all)	Very high (unmapped, but includes all)	Very high (unmapped, but includes all)	Not zoned						
Plant	Yes (unmapped, but includes all)	Moderate (unmapped, but includes all)	Moderate (unmapped, but includes all)	Not zoned (unmapped, but includes all)	Not zoned (unmapped, but includes all)	Moderate (unmapped, but includes all)	Moderate (unmapped, but includes all)	Moderate (unmapped, but includes all)	Very high (unmapped, but includes all)	Very high (unmapped, but includes all)	Very high (unmapped, but includes all)	Very high (unmapped, but includes all)	Not zoned						
Connection line	Yes (unmapped, but includes all)	Moderate (unmapped, but includes all)	Moderate (unmapped, but includes all)	Not zoned (unmapped, but includes all)	Not zoned (unmapped, but includes all)	Moderate (unmapped, but includes all)	Moderate (unmapped, but includes all)	Moderate (unmapped, but includes all)	Very high (unmapped, but includes all)	Very high (unmapped, but includes all)	Very high (unmapped, but includes all)	Very high (unmapped, but includes all)	Not zoned						
Number of reported distinct LOC incidents in Evans (2008) and in Folge et al. (2016)	0	0	0	0	1	1	2	1	3	1	0	3	1	0	1 (continuous surface leakage for years)	3			
1.4 Health and safety C/Q distances (meters)	9,124	9,813	7,977	9,686	9,102	9,743	9,282	9,553	9,116	8,598	8,608	12,037		8 - 6.5	0.9 - >0	0			
Proximity of handling plant (center) to well field (km)	0	0.7	6.5	0.9	8	0.3	0	0.4	0.2	0	0.5	x							
Population and sensitive receptors in proximity to UGS (USGS 50th percentile of C/Q)	609	401	23,771	848	195	223,859	6,473	8,821	325,330	188,359	108,371	1,864,128	195,399	1,005,939	50,000 - 69,999	100,000 - 200,000	300,000 - 400,000	500,000 - 600,000	
Daycare centers	82	17	1,499	41	0	15,640	1,868	365	12,211	11,129	6,409	113,126	3,929	1,000 - 9,999	10,000 - 20,000	20,000 - 30,000	30,000 - 40,000	40,000 - 50,000	
Schools	0	0	10	0	0	176	2	5	244	121	77	877	0	1 - 5	6 - 25	26 - 125	126 - 482	483 - 880	
Elderly care facilities	0	0	0	2	0	0	0	4	102	54	32	482	0						
Hospitals	0	0	2	0	0	92	0	0	130	61	41	59	85						
Median (max) formaldehyde emissions from 1996 - 2015, predominantly from compressors during routine operations (lb/yr)	4 (5)	108 (205)	1,291 (1,291)	not reported	not reported	4,868 (7,204)	11,163 (11,163)	not reported	15,001 (20,640)	2,197 (3,456)	3,038 (5,772)	1 (19,242)	1 - <100	100 - <1,000	1,000 - <10,000	10,000 - 100,000	100,000 - 1,000,000	1,000,000 - 10,000,000	
Average observed methane emission rate (kg CH ₄ /hr)	88	37	0	43	35	11	150	16	200 ¹	740	36	NA	NA or 0	11 - <30	30 - <90	90 - <270	270 - 740		
Extrapolated annual emissions/average annual gas injection (1%)	0.8	0.4	0	0.4	0.1	0.1	0.2	0.4	0.2 ²	1.2	0.1	NA	NA or 0	>0 - 0.3	>0.1 - 0.6	>0.3 - 0.9	>0.9 - 1.2		

¹Also emissions measured following repair of the 2015 blowout