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

Curtis M. Oldenburg and Preston D. Jordan
Energy Geosciences Division Lawrence Berkeley National Laboratory, Berkeley, CA

California Council on Science and Technology

December 2017

Long-Term Viability of Underground Natural Gas Storage in California

An Independent Review of Scientific and Technical Information

Jane C.S. Long, PhD, Independent Consultant
Steering Committee Co-Chair

Jens T. Birkholzer, PhD, Lawrence Berkeley National Laboratory
Steering Committee Co-Chair

Amber J. Mace, PhD, California Council on Science and Technology
Project Director

Sarah E. Brady, PhD, California Council on Science and Technology
Project Manager

Steering Committee Members

J. Daniel Arthur, P.E., SPEC, ALL Consulting L.L.C

Riley M. Duren, P.E., NASA Jet Propulsion Laboratory

Karen Edson, retired California Independent System Operator

Robert B. Jackson, PhD, Stanford University

Michael L.B. Jerrett, PhD, University of California, Los Angeles

Najmedin Meshkati, PhD, University of Southern California

Scott A. Perfect, PhD, Lawrence Livermore National Laboratory

Terence Thorn, JKM Energy and Environmental Consulting

Samuel J. Traina, PhD, University of California, Merced

Michael W. Wara, PhD, Stanford Law School

Non-Voting Ex Officio Steering Committee Members

Catherine M. Elder, M.P.P; Aspen Environmental Group (Technical Expert)

Jeffery Greenblatt, PhD; Lawrence Berkeley National Laboratory (Author)

Curtis M. Oldenburg, PhD; Lawrence Berkeley National Laboratory (Author)

Acknowledgments

This report has been prepared by the California Council on Science and Technology (CCST) with funding from the California Public Utilities Commission.

Copyright

Copyright 2017 by the California Council on Science and Technology ISBN Number: 978-1-930117-86-0 Long-Term Viability of Underground Natural Gas Storage in California: An Independent Review of Scientific and Technical Information

About CCST

The California Council on Science and Technology is a nonpartisan, nonprofit organization established via the California State Legislature in 1988. CCST engages leading experts in science and technology to advise state policymakers- ensuring that California policy is strengthened and informed by scientific knowledge, research, and innovation. CCST responds to the Governor, the Legislature, and other State entities who request independent assessment of public policy issues affecting the State of California relating to science and technology.

Note

The California Council on Science and Technology (CCST) has made every reasonable effort to assure the accuracy of the information in this publication. However, the contents of this publication are subject to changes, omissions, and errors, and CCST does not accept responsibility for any inaccuracies that may occur.

For questions or comments on this publication contact: California Council on Science and Technology 1130 K Street, Suite 280 Sacramento, CA 95814

916-492-0996

ccst@ccst.us www.ccst.us

Layout by a Graphic Advantage! 3901 Carter Street #2, Riverside, CA 92501

www.agraphicadvantage.com

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 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.

Facility[1]			Independents					Pacific Gas and Electric			Southern California Gas					Hazard highlighting ranges and categories (NA = not applicable or available)				
			Gill Ranch Gas	Kirby Hill Gas	Lodi Gas	Princeton Gas	Wild Goose Gas	Los Medanos Gas	McDonald Island Gas	Pleasant Creek Gas	Aliso Canyon	Honor Rancho	La Goleta Gas	Montebello	Playa del Rey	Lowest	Low	Medium	High	Highest
1.1 UGS Characteristics																				
Nearest incorporated city or cities			Mendota	Fairfield	Lodi & Galt	Willows	Gridley	Concord	Stockton	Winters	Los Angeles	Santa Clarita	Santa Barbara & Goleta	Montebello	Los Angeles					
County or counties (if a second county is listed, it only contains a portion of the connection line)			Madera & Fresno	Solano	San Joaquin & Sacramento	Colusa	Butte	Contra Costa	San Joaquin & Contra Costa	Yolo	Los Angeles	Los Angeles	Santa Barbara	Los Angeles	Los Angeles					
Owner/operator			Gill Ranch LLC (75%), PG&E (25%)	Rockpoint	Rockpoint	AGL (through Pivotal Energy Development)	Rockpoint	PG&E	PG&E	PG&E	SoCalGas	SoCalGas	SoCalGas	SoCalGas	SoCalGas					
Average depth (range) of storage reservoir(s) (ft)			5,850 - 6,216	1,550 - 5,400	2,280 - 2,515	2,170	2,400 - 2,900	4,000	5,220	2,800	9,000	10,000	3,950	7,650	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	1956	1942	2005 - 2012	1985 - 2004	1965 - 1984	1942 - 1964	
Capacity (Bcf)		2006	0.0	5.0	17.0	0.0	20.5	17.4	82.0	2.3	82.0	23.0	21.5	NA	2.6	2.3 - <3.0	3.0 - <10.0	10.0 - <30.0	30.0 - 82.0	
		2015	20.0	15.0	17.0	11.0	75.0	17.9	82.0	2.3	86.2	27.0	19.7	NA	2.4				30.0 - 86.2	
Average % capacity utilized annually - 2006 to 2015			35%	70%	128%	47%	50%	57%	45%	55%	69%	108%	56%	NA	159%	35% - <50%	50% - <80%	80% - <110%	110% - 159%	
Median tubing pressure per pool (psi; % of initial)			2,322 (89%) 2,399 (86%)	1,019 (89%) 1,560 (71%)	846 (86%) 931 (85%)	1,080 (106%)	1,251 (96%)	1,390 (79%)	1,850 (79%)	1,206 (95%)	2,280 (63%)	2,730 (61%)	1,676 (87%)	63 (initial pressure NA)	1,370 (50%)	63 - <1,300	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	NA	13	13 - <20	20 - <100	100 - <500	500 - 866	
Wells connected to storage reservoir open[2] in 2015	Number	Transferred gas during study period	12	18	17	8	17	21	81	7	111	38	17	20	34		7 - 9	10 - 25	25 - 74	75 - 111
		Did not transfer gas during study period	0	0	9	5	0	0	7	0	4	3	1	0	20	0	1 - 9	10 - 20		
	Age	Oldest (yrs)	5	40	72	61	16	41	78	66	75	59	85	x	84	5 - 24	25 - 49	50 - 74	75 - 85	
		Median (yrs)	5	7	13	4	7	36	41	41	42	39	63	x	79	4 - 24	25 - 49	50 - 74	75 -79	
Estimated number of groundwater wells to 2015 capacity (/Bcf)		Public and domestic	0.1	0.1	9.2	0.9	0.0	0.5	0.1	1.7	0.0	0.0	0.4	x	0.0	0.0 - 1.0	1.0 - <3.0	3.0 - <6.0	6.0 - 9.2	
		Total	1.4	1.2	11.6	3.4	0.0	1.7	1.1	5.4	0.0	0.3	2.9	x	5.0				6.0 - 11.6	
Depth of the base of fresh water (ft)		Maximum	950	1,850	2,485	1,870	1,000	2,140	100	2,270	Not available	Not available	None	x	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 applicable	x	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)		(ft)	510	195	693	400	Not available	320	290	870	No wells	145	1,270	x	No wells	NA	145 - <400	400 - <800	800 - 1,270	
		% of max. fresh water	51%	11%	24%	21%		15%	290%	36%		Not calculable	Infinite	x		11% - <25%	25% - <50%	50% - 75%	>75% - 290%	
% of public, domestic, and irrigation wells with BPI depth			100%	56%	47%	42%	0%	69%	56%	94%		75%	95%	x		NA and 100%	<100% - 80%	<80% - 60%	<60% - 42%	0%
CASGEM basin prioritization[3]			High	Very Low	High	Medium	Medium	None	Medium	High	Medium	Medium	None	x	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 DOGGR 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

Facility[1]		Independents					Pacific Gas and Electric			Southern California Gas					Hazard highlighting ranges and categories (NA = not applicable or available)				
		Gill Ranch Gas	Kirby Hill Gas	Lodi Gas	Princeton Gas	Wild Goose Gas	Los Medanos Gas	McDonald Island Gas	Pleasant Creek Gas	Aliso Canyon	Honor Rancho	La Goleta Gas	Montebello	Playa del Rey	Lowest	Low	Medium	High	Highest
1.2 Failure modes and likelihoods and hazards																			
Maximum deep-seated landslide susceptibility	Well(s) and field line(s)	0	VI	0	0	0	VI	0	VII	X	X	X	V	X	(0)	(V)	(VI) - (VIII)	(IX) - (X)	
	Connection line	0	VII	0	0	0	III	0	V	X	X	0	VII	X					
Last fault rupture through or (*) within 500 m of field line(s) (yrs ago)		None	<130,000	None	None	None	<130,000*	None	None	<15,000*	<15,000*	<130,000*	None	None	None	<130,000*	<130,000 - <15,000*	<15,000	
Hazard of Quaternary fault shearing of well(s) present		No	Yes	No	No	No	Maybe	No	No	Yes	Unlikely	Unlikely	No	No	No	Unlikely	Maybe	Yes	
Maximum 2% probability of exceeding 0.2-sec spectral acceleration in 50 years (g)	Well(s)	0.85	1.55	0.65	0.75	0.65	2.15	1.15	1.75	2.55	2.45	2.65	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	2.65	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	2.65	2.15	1.55					
	Connection line	1.45	1.55	1.25	0.95	0.65	2.15	1.25	1.85	2.75	2.45	2.65	2.15	1.55					
Maximum 2% probability of exceeding 1-sec spectral acceleration in 50 years (g)	Well(s)	0.45	0.55	0.35	0.45	0.45	0.85	0.75	0.85	1.45	1.15	1.55	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	1.55	1.05	0.95					
	Plant	0.45	0.55	0.35	0.45	0.35	0.75	0.75	0.75	1.45	1.05	1.45	1.05	0.85		0.35 - <0.50	0.50 - <1.00	1.00 - 1.45	
	Connection line	0.75	0.75	0.85	0.55	0.45	0.75	0.85	0.75	1.45	1.05	1.45	1.05	0.95					
Liquefaction hazard zone	Well(s) and field line(s)	? (unmapped, but on alluvium by river)	? (unmapped, but includes alluvium by slopes)	? (unmapped, but includes alluvium near slopes)	? (unmapped, but includes alluvium by slopes)	? (unmapped, but includes alluvium by slopes)	No (unmapped, but no alluvium or shallow slopes)	? (unmapped, but includes alluvium near slough)	? (unmapped, but includes alluvium by river)	No	Yes	? (unmapped, but includes alluvium by bluffs)	No	Yes	No		?	Yes	
	Plant									No	Yes		No	Yes					
	Connection line									Yes	Yes		No	Yes					
Earthquake-induced landslide hazard zone	Well(s) and field line(s)	No (unmapped, but little topographic relief)	? (unmapped, but includes slopes)	No (unmapped, but little topographic relief)	No (unmapped, but little topographic relief)	No (unmapped, but little topographic relief)	? (unmapped, but includes slopes)	No (unmapped, but little topographic relief)	No (unmapped, but little topographic relief)	Yes	Yes		No	Yes					
	Plant									No	No		No	Yes					
	Connection line									Yes	No		No	No					
Tsunami hazard	Well(s)	No	No	No	No	No	No	No	No	No	No	Yes	No	? (three observation wells assigned to the Del Rey Hills Area even though they are in the Venice Beach Area)					
	Field line(s)	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No			Yes	
	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					
Flooding hazard	Well(s) and field line(s)	No	No	No	No	Yes	No	Yes	No	No	No	Yes	No	No					
	Plant	No	No	No	Yes	No	No	Yes	No	No	No	No	No	No					
	Connection line	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No	No	No	No					
Fire hazard severity zones - predominant (maximum, if different)	Well(s)	Not zoned	Moderate	Not zoned	Not zoned	Not zoned	Moderate	Moderate	Moderate	Very high	Very high	Not zoned	Not zoned	Very high	Not zoned		Moderate		Very high
	Field line(s)	Not Zoned	Moderate	Not zoned (moderate)	Not zoned	Not zoned (moderate)	Moderate	Moderate	Moderate	Very high	Very high	Not zoned	Not zoned	Very high					
	Plant	Not Zoned	Moderate	Not zoned	Not zoned	Not zoned	Moderate	Not zoned	Moderate	Very high	Very high	Not zoned	Not zoned	Very high					
	Connection line	Not zoned (moderate)	Moderate	Not zoned (moderate)	Not zoned (moderate)	Not zoned (moderate)	Moderate	Not zoned (moderate)	Moderate	Very high	Very high	Not zoned	Not zoned	Not zoned (very high)					
Number of reported distinct LOC incidents in Evans (2008) and in Folga et al. (2016)		0	0	0	0	1	1	2	1	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	8,998	8,608	12,037	9,506					
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	0		8 - 6.5	0.9 - >0	0	
Population and sensitive receptors in proximity to UGS (QL50: 50th percentile of C/Q)																			
Total population		909	401	23,771	848	195	223,069	6,473	8,821	325,330	180,359	101,371	1,594,128	691,757	195 - 999	1,000 - 9,999	10,000 - 99,999	100,000 - 999,999	1,000,000 - 1,600,000
Children under 5		82	17	1,600	41	9	15,640	388	545	18,711	11,139	4,040	113,206	39,352	9 - 99	100 - 999	1,000 - 9,999	10,000 - 99,999	100,000 - 120,000
Daycare centers		0	0	10	0	0	176	2	9	244	121	77	877	577	0	1 - 5	6 - 50	51 - 500	>500 - 880
Schools		0	0	9	2	0	63	0	4	102	54	32	482	218			6 - 25	26-125	126 - 482
Elderly care facilities		0	0	2	0	0	92	0	0	130	61	41	59	85					126 - 130
Hospitals		0	0	0	0	0	3	0	0	4	1	3	26	9		1 - 2	3 - 6	6 - 18	19 - 26
Median (max) formaldehyde emissions from 1996 - 2015, predominantly from compressors during routine operations (lbs/yr)		4 (5)	108 (205)	1,291 (1,291)	not reported	not reported	4,968 (7,204)	11,163 (11,163)	not reported	15,001 (20,640)	18,675 (27,296)	2,197 (3,456)	1 (19,242)	3,038 (5,772)	1 - <100	100 - <1,000	1,000 <10,000	10,000 - 18,675	
1.5 GHG emissions																			
Average observed methane emission rate (kg CH4/hr)		88	37	0	43	35	11	150	16	200[3]	740	36	NA	0	NA or 0	11 - <30	30 - <90	90 - <270	270 - 740
Extrapolated annual emissions/average annual gas injection (%)		0.8	0.4	0	0.4	0.1	0.1	0.2	0.4	0.2[3]	1.2	0.1	NA	0	NA or 0	>0 - 0.3	>0.1 - 0.6	>0.3 - 0.9	>0.9 - 1.2

[3]Aliso emissions measured following repair of the 2015 blowout