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Long-Term Viability of Underground Natural Gas Storage in California

An Independent Review of Scientific and Technical Information

EXECUTIVE SUMMARY

A Commissioned Report prepared by the California Council on Science and Technology

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CALIFORNIA COUNCIL ON SCIENCE & TECHNOLOGY

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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.

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Long-Term Viability of Underground Natural Gas Storage in California

An Independent Review of Scientific and Technical Information

Executive Summary

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Executive Summary

In late 2015, southern California experienced a large natural gas leak that resulted in the displacement of thousands of residents in the surrounding community. An underground storage facility at Aliso Canyon, the second-largest facility of its kind in the United States, began leaking in October, and the Governor proclaimed a state of emergency on January 6, 2016. The leak was contained in February 2016. Approximately 100,000 tonnes of methane were emitted into the atmosphere.

To address part of the Governor's state of emergency proclamation, the State of California sought more information about all of the underground natural gas storage fields in California, and the California Council on Science and Technology (CCST) was asked to provide the State with an up-to-date technical assessment. In consultation with the California Public Utilities Commission (CPUC), the State Energy Resources Conservation Commission, the State Air Resources Board, and the Division of Oil, Gas, and Geothermal Resources, the assessment includes a broad review of the potential health risks and community impacts associated with their operation, fugitive gas emissions, and the linkages between gas storage, California's current and future energy needs, and its greenhouse gas reduction goals. A scope of work was developed that includes three key questions:

- **Key Question 1:** What risks do California's underground gas storage facilities pose to health, safety, environment and infrastructure?
- **Key Question 2:** Does California need underground gas storage to provide for energy reliability through 2020?
- **Key Question 3:** How will implementation of California's climate policies change the need for underground gas storage in the future?

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Study Process

CCST organized and led the study reported on here. Members of the CCST Steering Committee were appointed based on technical expertise and a balance of technical viewpoints. (Appendix C in the Summary Report provides information about CCST's

Steering Committee membership.) All experts who contributed to the study were evaluated for potential conflicts of interest. Under the guidance of the Steering Committee, a team of experts (science team) assembled by CCST developed the findings based on original technical data analyses and a review of the relevant literature. Appendix D in the Summary Report provides information about the science team. In order for the Steering Committee to oversee the work of the science team and develop recommendations and conclusions based on the findings of the science team, it was important for the Steering Committee to interact regularly with the lead science team members. Therefore, Steering Committee lead science team members were included as *ex officio* non-voting Steering Committee members.

The science team studied each of the issues identified in the scope of work, and the science team and the Steering Committee collaborated to develop a series of findings, conclusions, and recommendations defined as follows:

- **Finding:** Facts we have found that could be documented or referenced and that have importance to our study.

- **Conclusion:** A deduction we made based on findings.

- **Recommendation:** A statement that recommends what an entity should consider doing as a result of our findings and conclusions.

The committee process ensured that conclusions were based on findings (facts), and recommendations were based on findings and conclusions. Both the science team and the Steering Committee members proposed draft conclusions and recommendations. These were modified based on peer review and discussion within the Steering Committee, along with continued consultation with the science team. Final responsibility for the conclusions and recommendations in this Executive Summary lies with the Steering Committee. All Steering Committee members have agreed with these conclusions and recommendations. Any Steering Committee member could have written a dissenting opinion, but no one requested to do so. The conclusions and recommendations expressed in this publication are those of the Steering Committee, and do not necessarily reflect the view of the organizations or agencies that provided support for this project.

The full report, including the summary report, has undergone extensive peer review; peer reviewers are listed in Appendix H of the Summary Report, "Expert Oversight and Review." Fourteen Reviewers were chosen for their relevant technical expertise. More than 1,150 anonymous review comments were provided to the science team and Steering Committee (study team). The study team revised the report in response to peer review comments. A report monitor, appointed by CCST, then reviewed the response to the review comments and when satisfied, approved the report.

Overview

The underground natural gas storage system in California today provides essential energy reliability services. California's underground gas storage (UGS) facilities send gas to customers when the State's gas pipelines cannot import gas fast enough to meet consumer demand. These facilities store gas during periods of low demand and make fuel available during periods of high demand, for example for heating on cold winter days or generating electricity for air conditioning on hot summer days. The current configuration of the energy system in California requires essentially all of the State's available underground gas storage capacity, and this complex system works very well from an energy reliability perspective. Currently, underground gas storage facilities regularly obviate the need for California to curtail natural gas delivery during multiday cold winter conditions, provide for storage of natural gas in the summer to meet the total winter season demand, allow for smooth daily operations of electric generators despite intermittent contributions from solar and wind sources, and provide price arbitrage opportunities that can save money for California's consumers.

Although the need for underground gas storage might be reduced in the coming decades in a variety of ways, we found no immediate practical measures that would overcome California's demand for natural gas during peak periods in the winter—a demand that currently exceeds the State's pipeline capacity to import gas. In a post-2020 timeframe, these facilities could be completely replaced with either more pipelines or gas peak-shaving (surface gas storage) units, but not without significant expense (approximately $10-15B capital expenditure), and importantly, not without taking on a new set of incremental risks associated with additional pipelines and associated gas compression systems. To provide some context for this, we note that overall expenditures in California for natural gas are about $10B/year.

In late 2015, the major well blowout at the Aliso Canyon underground gas storage facility illustrated the risks posed by loss-of-containment at underground gas storage facilities (underground gas storage). The Aliso Canyon leak was contained in February 2016, after approximately 100,000 tonnes of methane as well as unknown quantities of other pollutants had leaked into the atmosphere. This loss-of-containment incident caused considerable risks to worker safety and public health.

In the aftermath of the Aliso Canyon well blowout, California moved ahead to develop emergency regulations for all existing underground gas storage facilities in the State. New permanent regulations developed by California's Division of Oil, Gas and Geothermal Resources (DOGGR) will supersede these emergency regulations in January 2018. While many recommendations for further improvement of these regulations are made in this Executive Summary and in Chapter 1 of the report, the emergency regulations now in place and the final ones under development represent a major step forward to reduce the risks to health, safety, environment, and energy infrastructure of underground gas storage facilities, provided these new rules are consistently and thoroughly applied and enforced across all storage facilities. In the future, the effectiveness of the new regulations should be evaluated on a regular basis by an independent peer review or audit program.

Because of the flammability of natural gas and its storage and transport at high pressure, each of the twelve underground gas storage facilities in California presents some non-zero amount of risk to health, safety, the environment, and the underground gas storage infrastructure itself. We have compared the hazards and vulnerabilities of individual facilities based on a set of qualitative risk-related characteristics (Table ES.1-1). For example, facilities that have older repurposed wells (often in former oil reservoirs), have a higher number of reported loss-of-containment incidents, are located in seismic or other natural disaster hazard zones, or are located near large population centers pose relatively greater risks. The Playa del Rey facility, which has a long history of loss-of-containment incidents and is located near a large population center in a very high wildfire hazard zone, 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 higher health and safety risks than other facilities because of their locations near large numbers of people.

The new regulations for underground gas storage require each facility to develop and implement risk management plans comprising two major elements: risk assessment studies as well as intervention and prevention protocols. This requirement allows regulators to thoroughly evaluate how underground gas storage facilities identify and quantify risks and how these insights are translated into appropriate risk management practices. Each facility needs to conduct a robust *quantitative* risk assessment, which should include the key human, organizational, and technological subsystems, and that each facility should start immediately to develop risk targets that will ultimately guide risk-mitigation decision-making. Quantitative risk assessments will also provide further insight into quantitative risk differences between facilities. The State will be able to use this quantitative risk-related information on each facility to assess the tradeoffs between risks associated with individual facilities and their importance in meeting the demands of the natural gas supply.

Some sites may pose risks that are difficult to mitigate and large enough to warrant closing the facility. However, in many cases implementing better practices can mitigate the largest risks. For example, in facilities like Aliso Canyon, withdrawal of gas occurred in the past both through a production tube in the well and in the annulus outside of this tubing. This means that a single point of structural failure in the well could lead to a loss-of-containment, as in fact appears to have caused the 2015 Aliso Canyon incident. The new DOGGR well regulations significantly decrease the likelihood of well failure and loss of containment because they require at least two barriers between high-pressure fluids in the well and the surrounding environment. This means that at least two structural elements of the well (either the tubing and the casing or the packer and the casing) would have to fail simultaneously to cause a loss-of-containment rather than just one. If the SS-25 well at Aliso Canyon had been operated with two barriers for containment rather than one, a corrosion hole in the casing would not have caused a major blowout because the packer and the tubing would still contain the high-pressure gas. DOGGR estimates the cost of implementing these new regulations will be about $250M/year.

We emphasize that the State needs to weigh the risks associated with underground gas storage against the benefits, and that the State needs to compare potential alternatives to underground gas storage in a similar risk-benefit framework. The State should evaluate the risks posed and specific benefits provided by each *individual* gas storage facility. If risks cannot be mitigated to an acceptable level, then the State could evaluate other options to retain reliability of gas supply. Options could include building compensating infrastructure (for example, by adding peak-shaving units) or determining through detailed time-of-use assessment and hydraulic modeling of pipeline gas flows whether it is possible to do without the specific facility or use it less. (A preliminary example model of this type was produced for this report and described in Appendix J of the Summary Report.)

In the near term, no method of conserving or supplying electricity—including electricity storage (batteries, pumped hydroelectric, compressed air storage, etc.), new transmission, energy efficiency measures, and demand response—can replace the need for gas to meet the winter peak in the 2020 timeframe. The winter peak is caused by the demand for heat, and heat will continue to be provided by gas, not electricity, in that timeframe. Gas storage is likely to remain a requirement for reliably meeting winter peak gas demand.

Looking to the future, California may be able to reduce the need for natural gas, but cannot count on the implementation of its climate policies to fully eliminate the need for gas storage. California plans to increase its renewable energy portfolio to half of all power generation by 2030, while cutting greenhouse gas (GHG) emission by 40% and, per executive order, is also required to reduce emissions to 80% below 1990 levels by 2050. These significant changes raise as yet unanswered questions about how energy system integration and reliability will be accomplished, and what role natural gas, or other gases requiring storage, will play in that endeavor.

By 2030, California will likely use less natural gas overall than today as renewable energy displaces gas-fired electricity generation. However, if that renewable energy supply has similar characteristics to today's portfolio (domestic onshore wind and solar photovoltaic), then the availability of renewable energy will dip significantly in the winter because of reduced solar insolation and slower wind speeds, exactly when the peak need for gas heating occurs, and at other times when the sun is not shining and the wind is not blowing (conditions known as *dunkleflaute* from the German for "dark doldrums"). These conditions could create a need for gas-fired electricity to back up the intermittent renewable energy during cold winter weather, exactly. Thus, absent yet-to-be-identified or deployed seasonal energy storage technologies, electricity reliability will likely require some sort of gas generation and storage function.

The 2050 goals create even more uncertainty about the use of gas. Again, if the renewable energy portfolio looks much as it does today, estimates indicate that California may require nearly as much gas-fired as renewable electricity generation capacity just to ensure electricity reliability. Scenarios that might significantly reduce the need for gas storage would make use of a broader set of energy resources and strategies, such as geothermal, wave-power, imported renewables, a regionalized electricity system, energy storage, renewables curtailment, price responsive demand, or nuclear power. Such resources could provide firm low-greenhouse gas (GHG) electricity, reduce the need for load balancing, and consequently reduce the need for natural gas.

Alternatively, California could meet 2050 goals in ways that increase the need for underground gas storage. For example, gas-fired power plants with carbon capture and storage (CCS)—whereby the carbon dioxide (CO_2) from combustion would be captured and stored underground—may be a cost-effective alternative for meeting emission goals while also meeting energy demand. The CCS approach would likely increase the need for natural gas storage as well as require underground storage of CO_2. Approaches that replace the use of natural gas with lower-GHG alternatives, such as biomethane or hydrogen, would also not reduce the need for underground storage to manage these gases.

The current natural gas system works to provide reliable energy for California. However, changes planned to achieve the State's climate goals and actions taken to address problems revealed by the 2015 Aliso Canyon incident have the potential to disrupt this system. The State needs to closely examine the future of California's energy system as a whole (including tradeoffs among electricity, heat, and transportation demands). California policy makers should develop future scenarios that include detailed information about the time of use of both electricity and natural gas. Scenarios should assess the impact of increasing electrification in all sectors and the possible role for gas with CCS in supplying that electricity generation, incorporate explicit analysis of gas flows, determine the impact of electric regionalization and more dispatchable or firm forms of electricity, and do this on timescales that range from seconds to years. Such analysis would put planning for energy reliability in general, and specifically gas storage, on a much firmer footing.

In summary:

Conclusion ES-1: The risks associated with underground gas storage can be managed and, with appropriate regulation and safety management, may become comparable to risks found acceptable in other parts of the California energy system.

Recommendation ES-1: The State should ensure timely and thorough implementation of the new DOGGR regulations at each underground gas storage facility, emphasizing risk and safety management plans, quantitative risk assessment studies, risk mitigation and prevention, requirements for well integrity testing and monitoring, human and organizational factors, and a robust and healthy safety culture. To evaluate the effectiveness of the new regulations and the rigor of their application in practice, the State should implement an independent and mandatory review program for the new regulations, should publish the review results in publicly available reports, and should provide an opportunity for public comment.

Conclusion ES-2: California's energy system currently needs natural gas and underground gas storage to run reliably. Replacing underground gas storage in the next few decades would require very large investments to store or supply natural gas another way, and such new natural-gas-related infrastructure would bring its own risks. The financial investment would implicitly obligate the State to the use of natural gas for several decades.

Recommendation ES-2: In making decisions about the future of underground natural gas storage, the State should evaluate tradeoffs between the quantified risks of each facility, the cost of mitigating these risks, and the benefits derived from each gas storage facility- as well as the risks, costs, and benefits associated with alternatives to gas storage at that facility.

Conclusion ES-3: Some possible future energy systems that respond to California's climate policies might require underground gas storage—including natural gas, hydrogen, or carbon dioxide—and some potentially would not. California's current energy planning does not include adequate feasibility assessments of the possible future energy system configurations that both meet greenhouse gas emission constraints and achieve reliability criteria on all timescales, from subhourly to peak daily demand to seasonal supply variation.

Recommendation ES-3: The State should develop a more complete and integrated plan for the future of California's energy system, paying attention to reliability on all timescales in order to understand how the role of natural gas might evolve and what kind of gases (e.g., natural gas or other forms of methane, hydrogen, or carbon dioxide) may need to be stored in underground storage facilities in the future.

Please see the Summary Report for discussion of many additional findings, conclusions, and recommendtions.

Table ES-1.1. Selected comparative risk-related characteristics for California underground gas storage 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.

		Independents					Pacific Gas and Electric			Southern California Gas			
	Facility[1]	**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**	**Playa del Rey**
UGS facility characteristics	2015 Capacity (Bcf)	20.0	15.0	17.0	11.0	75.0	17.9	82.0	2.3	86.2	27.0	19.7	2.4
	Average depth (range) of storage reservoir(s)	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	6,200
	Average annual gas transfer per well per from 2006 to 2015 (million scf)	150	69	511	78	866	255	75	22	197	244	232	13
	Number of wells connected to storage reservoir in 2015	12	18	26	13	17	21	88	7	115	41	18	20
	Median age of wells as of 2015 (yrs)	39	9	15	6	11	36	41	41	60	56	63	80
Failure modes, likelihoods, and hazards	Maximum deep-seated landslide susceptibility	0	VII	0	0	0	VI	0	VII	X	X	X	X
	Last fault rupture through or (*) within 500 m of flow line(s) (yrs ago)	None	<130,000	None	None	None	<130,000*	None	None	<15,000*	<15,000*	<130,000*	None
	Hazard of Quaternary fault shearing of well(s) present	No	Yes	No	No	No	Maybe	No	No	Yes	Unlikely	Unlikely	No
	Max. 2% probability of exceeding 0.2-sec spectral acceleration in 50 years (g)	1.45	1.55	1.25	0.95	0.65	2.15	1.25	1.85	2.75	2.45	2.65	1.65
	Earthquake-induced landslide hazard zone	No	?	No	No	No	?	No	No	Yes	Yes	?	Yes
	Tsunami hazard	No	No	No	No	No	No	No	No	No	No	Yes	?
	Flooding hazard	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	No
	Fire hazard severity zones - predominant (maximum, if different)	Not zoned (moderate)	Moderate	Not zoned (moderate)	Not zoned (moderate)	Not zoned (moderate)	Moderate	Not zoned (moderate)	Moderate	Very high	Very high	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	3
Health and safety	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	0
	Population in proximity to UGS	909	401	23,771	848	195	223,069	6,473	8,821	325,330	180,359	101,371	691,757
	Median (max) formaldehyde emissions from 1996 - 2015, predominantly from compressors (lbs/yr)	4 (5)	108 (205)	1291 (1291)	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)	3,038 (5,772)
GHG emissions	Average observed methane emission rate (kg CH4/hr)	88	37	0	43	35	11	150	16	200[2]	740	36	0
	Extrapolated annual emissions/average annual gas injection (%)	0.8	0.4	0	0.4	0.1	0.1	0.2	0.4	0.2[2]	1.2	0.1	0

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

[2]Aliso emissions measured following repair of blowout

Concluding Remarks

The California Legislature mandated this study in mid-2016, and CCST conducted the study in a eleven-month period ending December 2017. Effectively, the research was conducted over a very short period of about seven months. CCST could not fully investigate many issues raised by the study because of time constraints. In addition, the study predates the availability of some pertinent information, specifically the results of the root-cause analysis of the 2015 Aliso Canyon incident. Because of the need to publish the report by December 2017, several topics will likely require further exploration.

CCST could not investigate the feasibility and impacts on reliability of closing one or more underground gas storage sites in the State while leaving the others open. For example, the Playa del Rey facility apparently does not store or withdraw a large amount of gas, providing only about 1% of total natural gas storage across California. However, Playa del Rey is close to a densely populated area, and the risk of loss-of-containment at Playa del Rey is higher than most other natural gas storage facilities. Our report questions, but does not answer, the impact of closing this site. The State should commission a cost-benefit analysis including full consideration of risks associated with loss-of-containment from this facility.

We also recommend a detailed research study of how California's natural gas system functioned during the several-month shutdown of Aliso Canyon. Researchers should document where the natural gas came from (e.g., other storage facilities, pipelines, etc.) that otherwise would have been supplied by Aliso Canyon, and what the weather conditions were during this interval that impacted demand in both cold and hot weather, and supply from renewable sources. The conditions over the last two years should be compared to historical conditions and the specific conditions required for reliability planning. Such a study would provide important insight about the utility of Aliso Canyon and data for stakeholders about whether Aliso Canyon should remain open.

The State deserves an assessment of these storage facilities based on the best available data and should strive to improve data transparency and availability for follow-on studies. The Steering Committee and investigators made several requests for data in the course of this assessment. The report findings reflect data we were able to obtain. In a number of cases we requested data and did not receive them. For example, daily injection and withdrawal data would help to assess hazards related to loss of well integrity, but DOGGR has these data available only on a monthly basis. The team also requested facility-specific data on withdrawn gas composition, or in the case of the 2015 Aliso Canyon incident, the composition of the gas escaping from the (SS-25) well blowout. An assessment of human health hazards for populations exposed to gas emitted from underground gas storage facilities requires knowing the composition of the gas (including specific trace chemicals: benzene, hydrogen sulfide and others listed in Appendix 1.E of Chapter 1), but the team could not obtain this detailed information. Apparently, operators do not collect these data as discussed in Appendix 1.E. of Chapter 1.

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