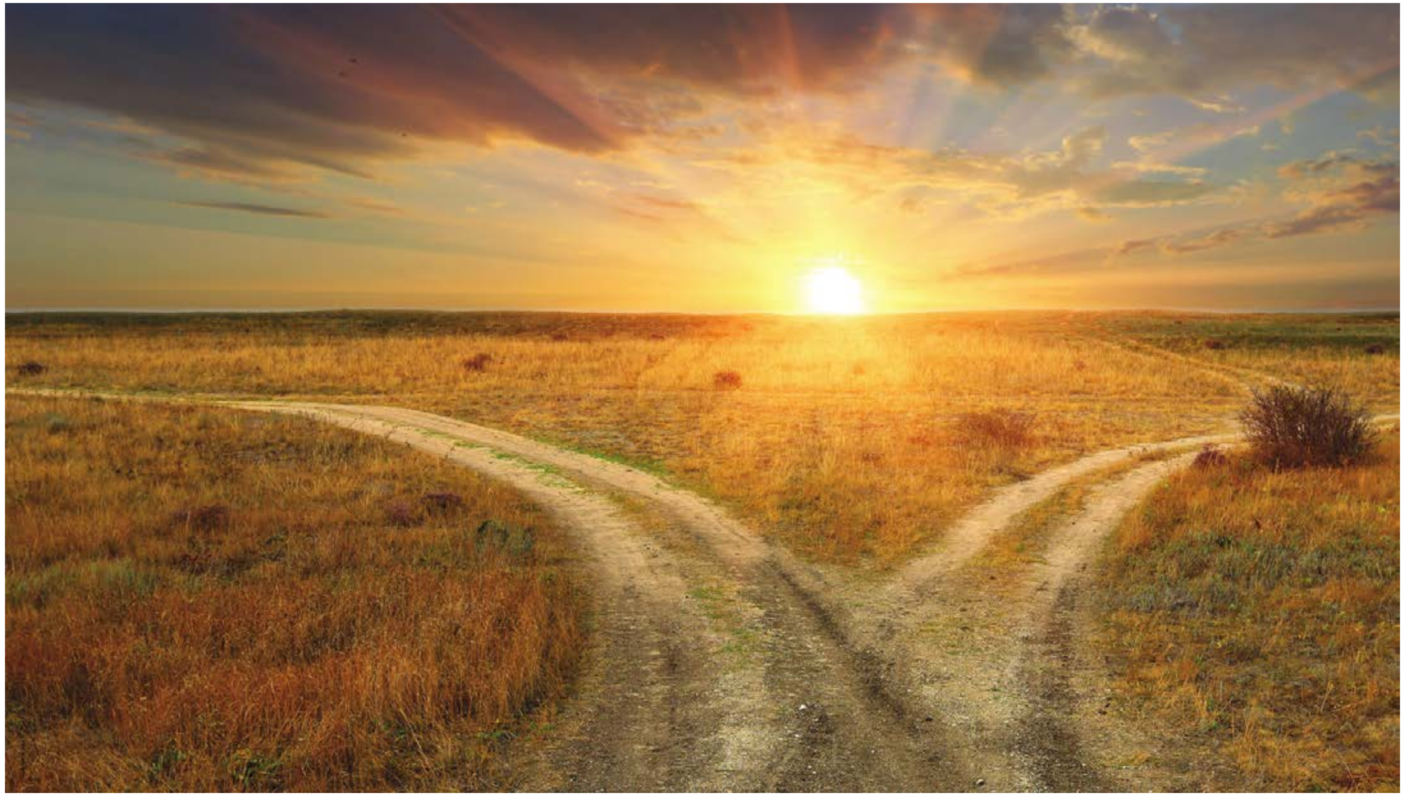
Long-Term Viability of Underground Natural Gas Storage in California

An Independent Review of Scientific and Technical Information



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Overview

- **Welcome and Introductions**– *Dr. Amber Mace, Project Director*
- **Study Process** - *Dr. Jane Long, Co-Chair*
- **Qualitative Comparison of the Risks of Individual Storage Fields** – *Dr. Curt Oldenburg, Lead Author*
- **Public Health** – *Dr. Seth Shonkoff, Author*
- **UGS for Energy Reliability** – *Dr. Jane Long, Co-Chair*
- **Possible Future Pathways** – *Dr. Jeffery Greenblatt, Lead Author*

- **Questions**

Study Request

In response to Governor Brown's January 2016 state of emergency proclamation regarding the Aliso Canyon gas leak, Governor Brown directed the following agencies to submit a report that assesses the long-term viability of natural gas storage facilities in California:

- Division of Oil, Gas and Geothermal Resources (DOGGR)
- California Public Utilities Commission (CPUC)
- California Air Resources Board (CARB)
- California Energy Commission (CEC)

Via Senate Bill 826, the Budget Act of 2016, the California Council on Science and Technology was asked to enter into a contract with the CPUC to conduct this study.

California Council on Science and Technology (CCST)

- CCST is a nonpartisan, impartial, not-for-profit corporation established via Assembly Concurrent Resolution (ACR 162) in 1988 to provide objective advice from California's scientists and research institutions on policy issues involving science.

- CCST is dedicated to providing impartial expertise that extends beyond the resources or perspective of any single institution.

- CCST is governed by a Board of Directors and studies are funded by government agencies, foundations, and other private sponsors.

Sustaining Institutions

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California Community Colleges

CalTech

California State Universities

Stanford University

University of California

Sandia National Labs

Lawrence Livermore National Lab

National Accelerator Laboratory

Lawrence Berkeley Laboratory

Jet Propulsion Laboratory

NASA Ames Research Center

National Renewable Energy Laboratory

California Council on Science and Technology (CCST)

In recent years, CCST has produced a series of reports on hydraulic fracturing, water, energy, and STEM education in California.

Our role is to oversee a very rigorous process. This involves:

- Convening the most relevant experts to put together a robust and balanced team
- Addressing any potential conflict of interest issues
- And conducting an extensive and rigorous peer review

This process, modeled after the National Academy of Sciences, ensures the produce is credible and responsive to the study charge.

Our goal is to provide credible, relevant and useful science-based information to inform State decision making.

Study Purpose and Key Questions

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Conduct an independent scientific assessment of the past, present, and potential future uses of underground natural gas storage in California

- **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 in the near term (through 2020)?
- **Key Question 3:** How will implementation of California's climate policies change the need for underground gas storage in the future?

CCST's Underground Natural Gas Storage Steering Committee

- Provided oversight, scientific guidance and input for the project
- Developed consensus conclusions and recommendations

Jane C.S. Long	LLNL (ret)	Co-Chair
Jens T. Birkholzer	LBNL	Co-Chair
J. Daniel Arthur	ALL Consulting LLC	Gas injection and well integrity
Riley M. Duren	JPL	Methane emissions
Karen Edson	Retired CAISO	Electric grid operations
Robert B. Jackson	Stanford	Energy use and climate change
Michael L.B. Jerrett	UCLA	Public Health
Najmedin Meshkati	USC	Risk reduction and reliability
Scott A. Perfect	LLNL	Mechanical engineer, safety
Terence Thorn	JKM Consulting	Natural gas industry
Samuel J. Traina	UC Merced	Environmental engineering
Michael W. Wara	Stanford	Energy and environmental law
Ex Officio:		
Curtis M. Oldenburg	LBNL	Lead Author, Chapter 1
Catherine M. Elder	Aspen	Technical Expert, Chapter 2
Jeffery B. Greenblatt	LBNL	Lead Author, Chapter 3

Study Authors

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- Analyzed and synthesized project-relevant data and drafted the report

  - Lawrence Berkeley National Lab (LBNL)
  - Aspen Environmental Group (Aspen)
  - ALL Consulting, LLC
  - Los Alamos National Lab (LANL)
  - JKM Energy and Environmental Consulting
  - Sandia National Laboratory
  - University of California Berkeley
  - National Institute of Standards and Technology (NIST)
  - Physicians, Scientists, and Engineers for Healthy Energy (PSE)
  - Walker & Associates
  - Energy Projects Consulting

The Basis of our Assessment

- Peer-reviewed published literature.
- Analysis of available data from DOGGR, CPUC, CARB and other publicly available sources.
- Other relevant publications including reports and theses. We state the qualifications of the information used in the report.
- The expertise of the committee and scientific community to identify issues.

Key Question 1

What risks do California's underground gas storage facilities pose to health, safety, environment and infrastructure?

Focus of Talk:

Comparative Risk-Related Characteristics Table 7.1-1

Dr. Curtis M. Oldenburg
Lawrence Berkeley National Laboratory
Lead Author

Key Question 1 Sub-topics

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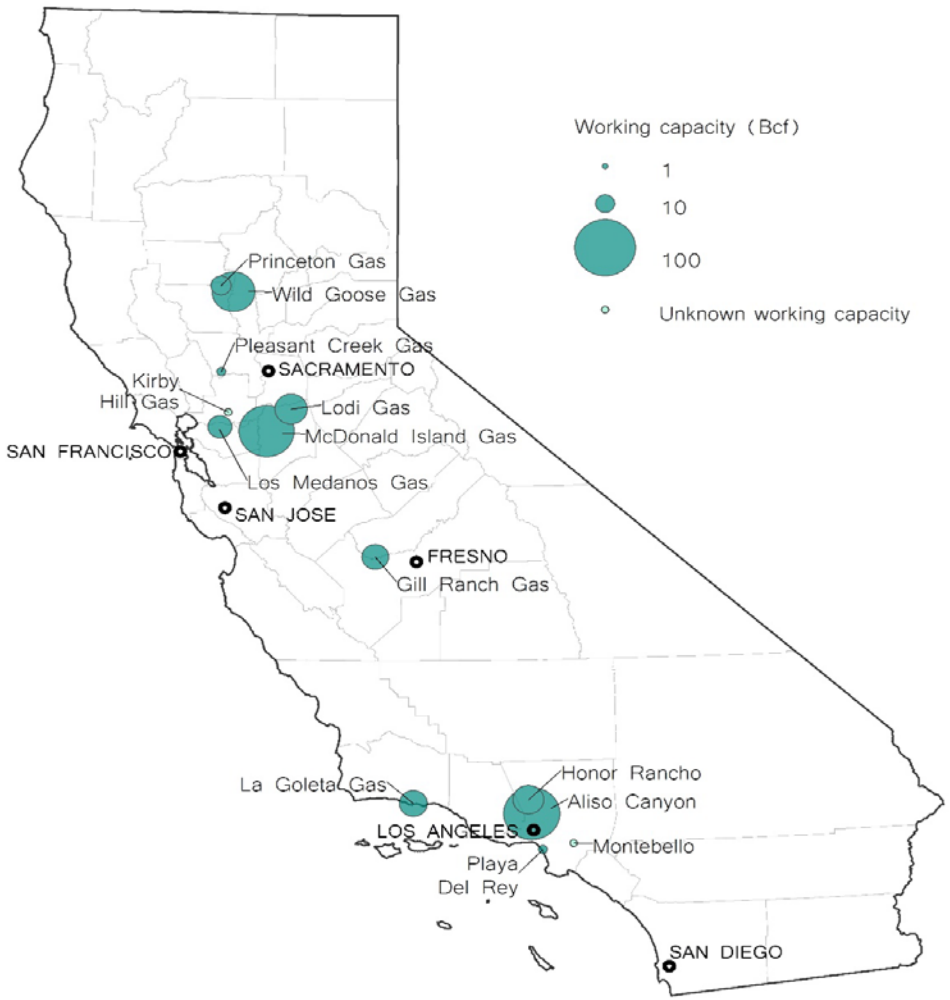
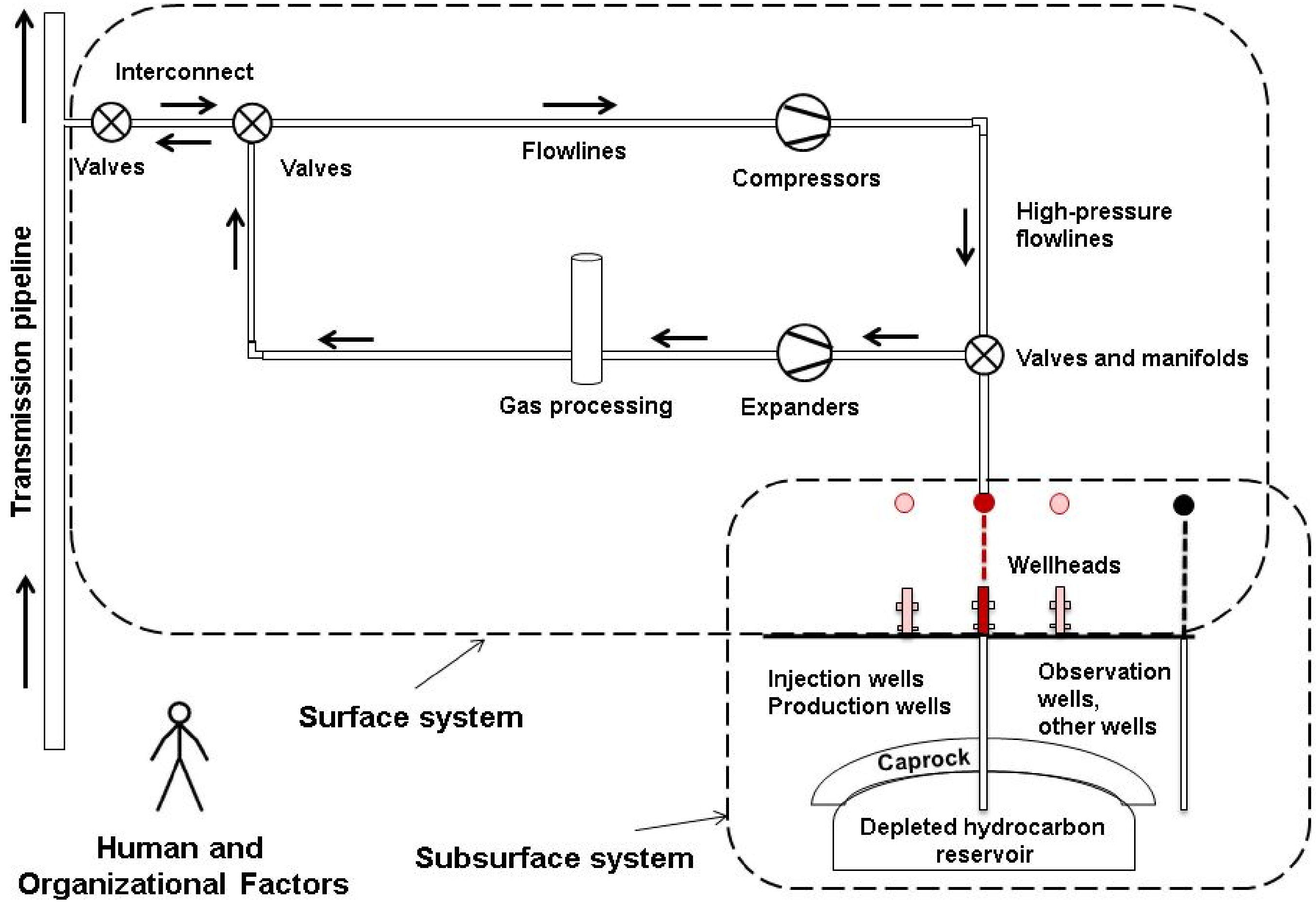
- Characteristics of different storage sites
- Potential failure modes
- Expected trends in capacity
- Human health risks
- Climate impacts of leakage
- Effect of regulatory changes

12 UGS facilities operate in California





~400 UGS wells of various ages are used

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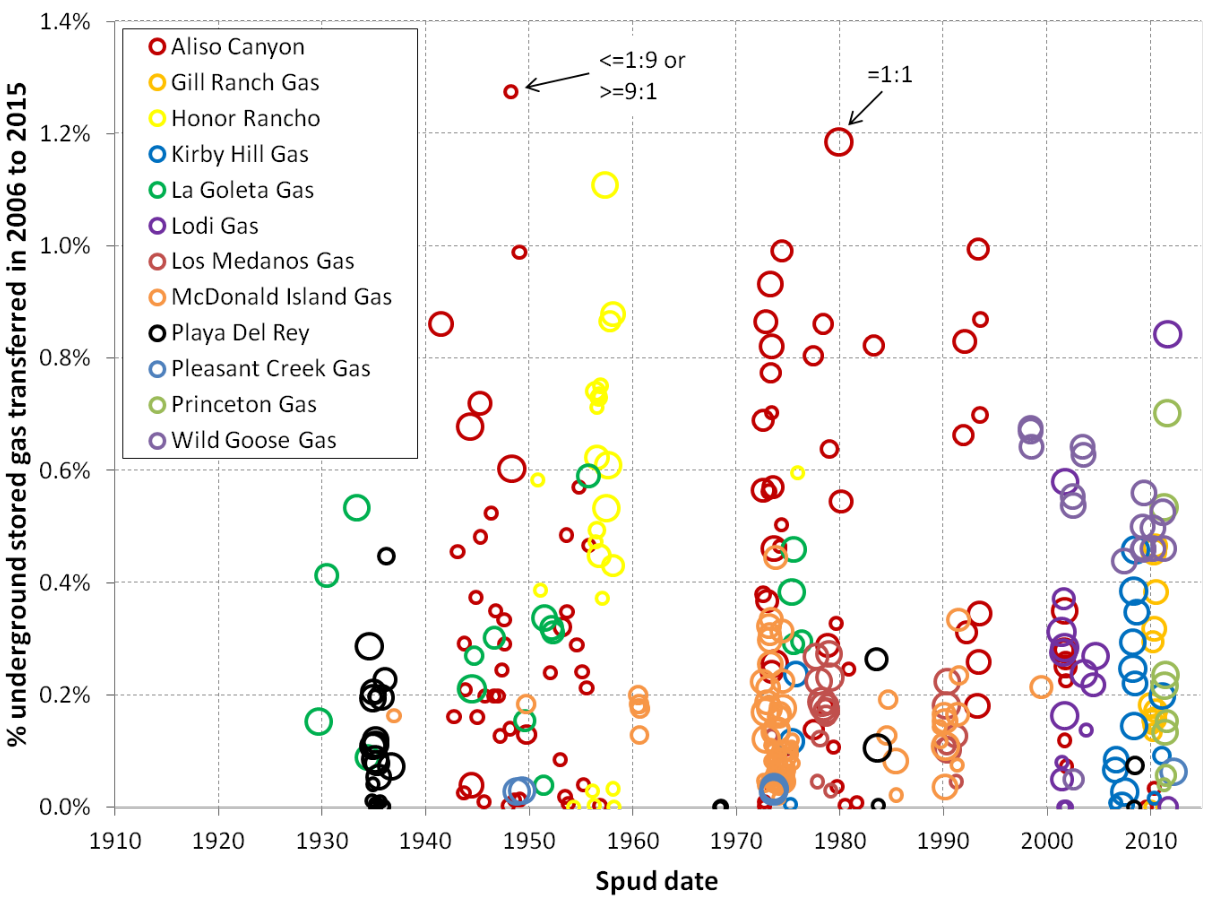

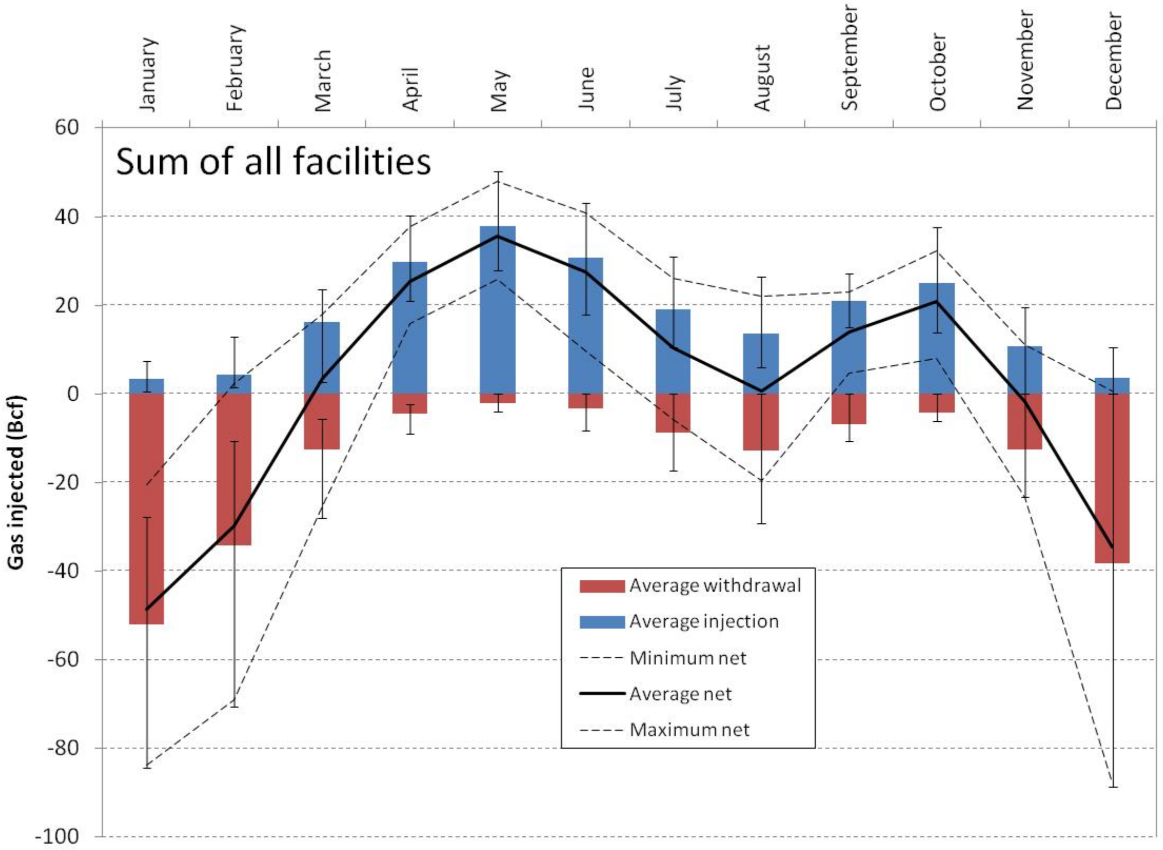

The size of the symbol indicates the ratio of withdrawal and injection in each well

UGS wells in California historically used whole diameter of well for flow

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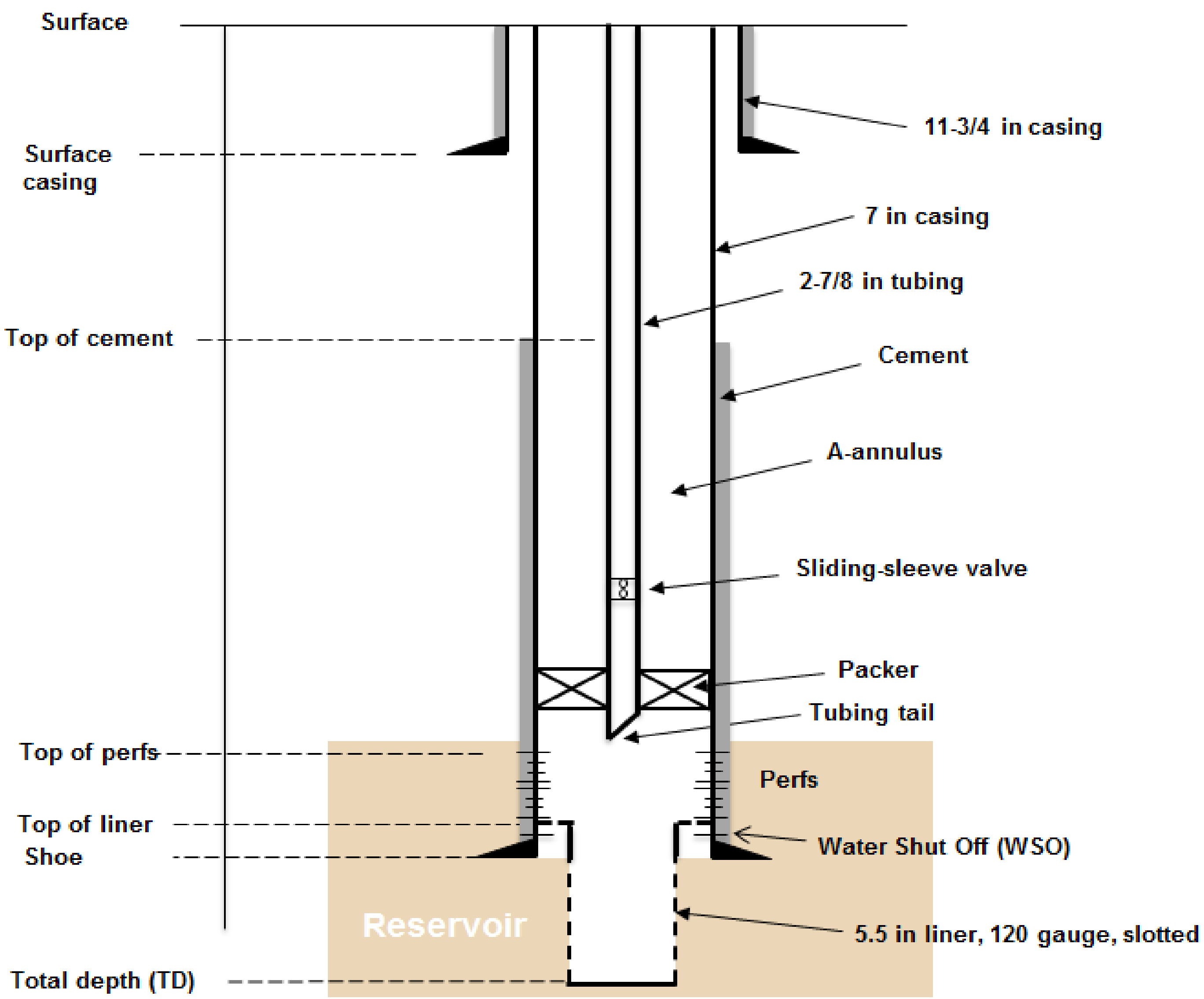
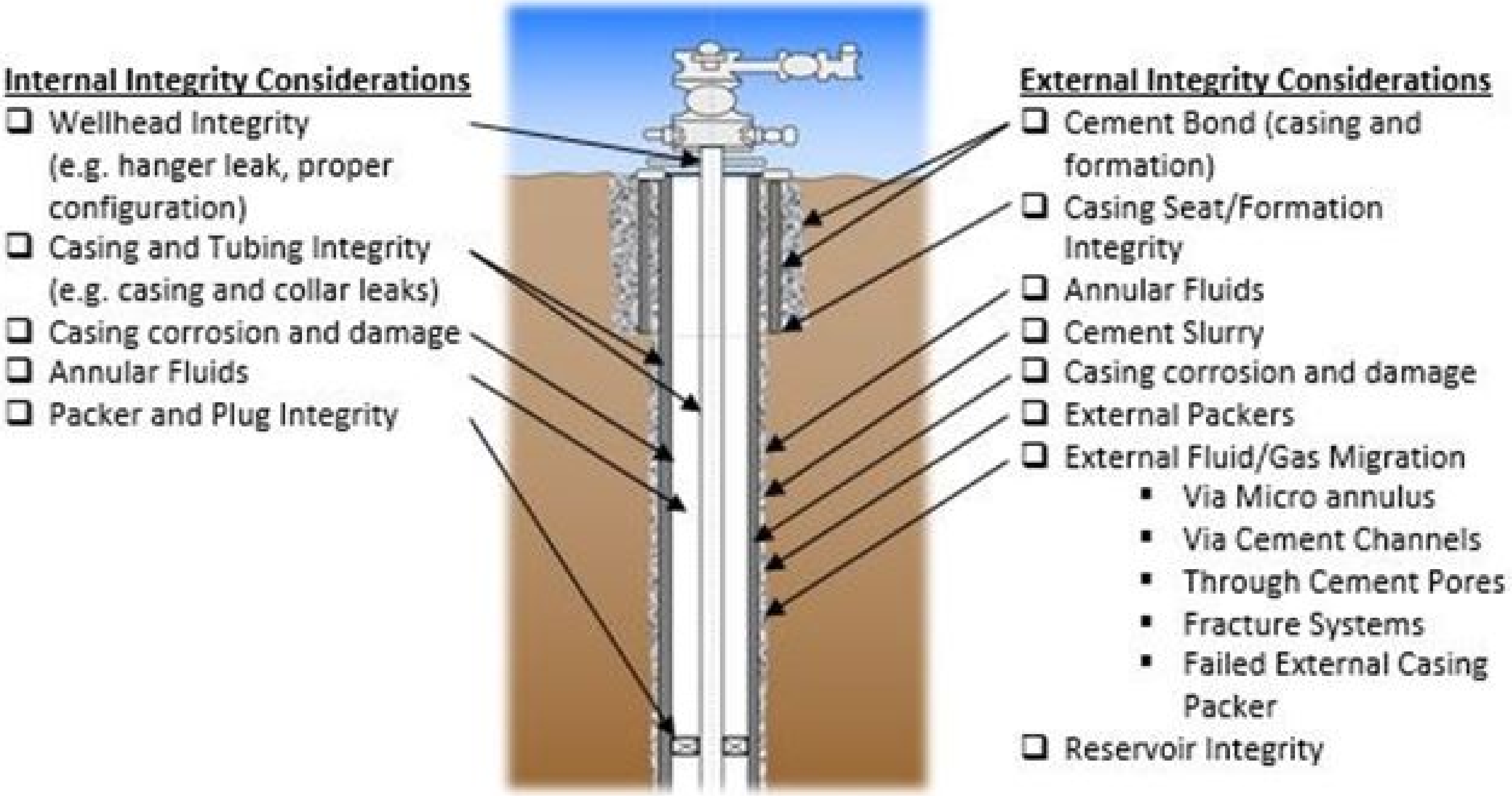


Incidents of loss of containment have historically been mostly related to wells



Source: ALL Consulting, 2017

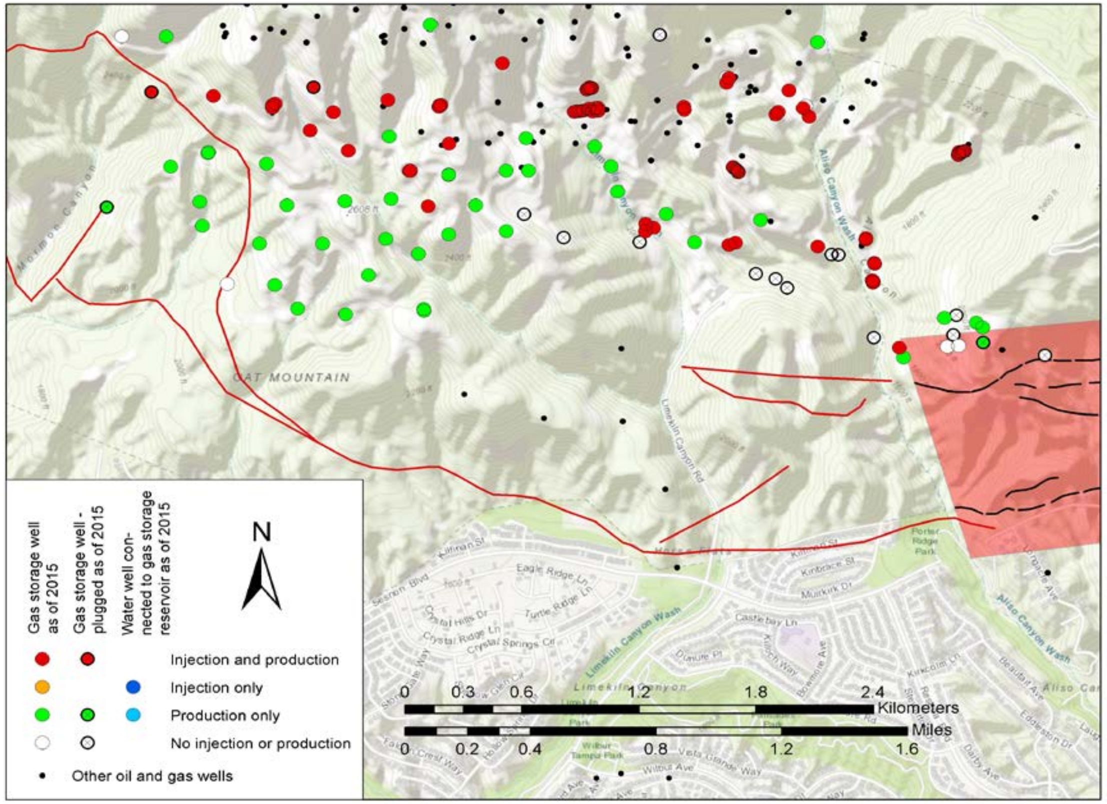
The new DOGGR regulations requiring tubing and packer will greatly reduce likelihood of well loss of containment.

Various external hazards can cause risk at UGS facilities

External hazards

(not intrinsic to gas storage)

- **Seismic**
- **Landslide**
- **Flooding**
- **Tsunami**
- **Wildfire**



Earthquake Fault Zone (EFZ) at the Aliso Canyon facility shown in red tint. Fault traces that ruptured during the last 15,000 years are shown in black, and traces that show evidence for activity during the last 130,000 years are shown in red.

Human health hazards are associated with loss of containment

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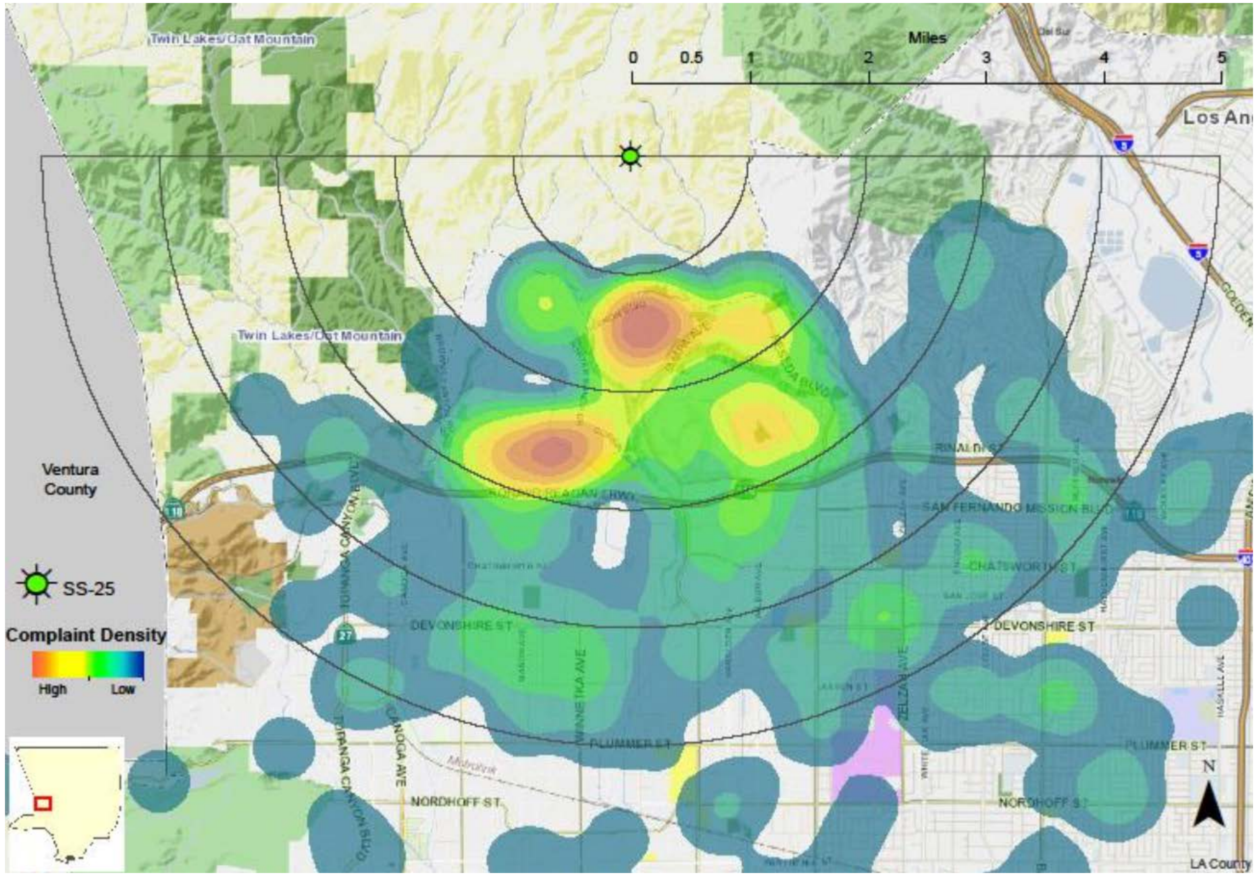
- Exposures to toxic air pollutants (e.g., benzene, toluene, xylene, hydrogen sulfide, mercaptans)

- Explosions and fires

2015 Aliso Canyon incident caused large-scale public health complaints

2015 Aliso Canyon incident was a large disaster that presented significant human health hazards

- Largest leak in US history
- Thousands relocated
- Affected health of tens of thousands of people
- Human exposures to toxic air pollutants not certain

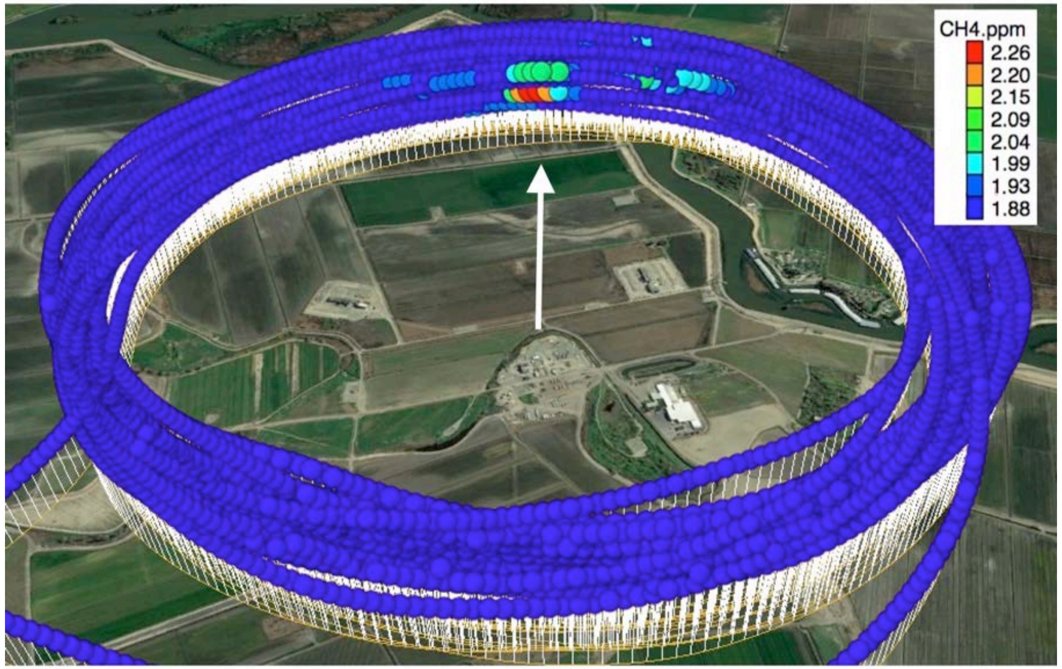


(LACDPH, 2016c)

Density of complaints

Methane emissions from UGS are less than 10% of other natural gas sources

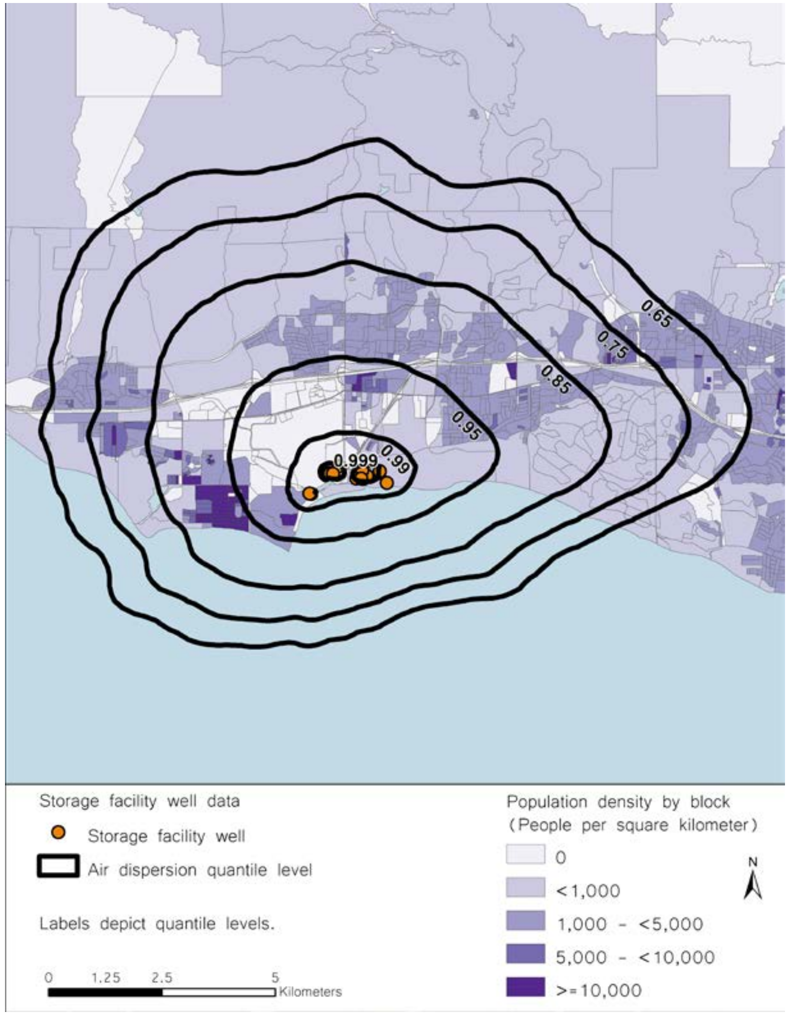
- Measured total UGS methane emissions are 1,060 kg/hr (~9.3 GgCH_4 (~0.5 Bcf annually))
  - ~7.8% of total natural gas-related emissions
  - ~0.5% total California CH_4 emissions
  - ~0.05% of total California GHG emissions
- Three facilities currently dominate emissions:
  - Honor Rancho 45%
  - Aliso Canyon (after the SS-25 repair) 16%
  - McDonald Island 14%
- Normal emissions are roughly equivalent to having a 2015 Aliso Canyon incident every 10 years



Flight paths above McDonald Island

Dispersion strongly dilutes leaking gas

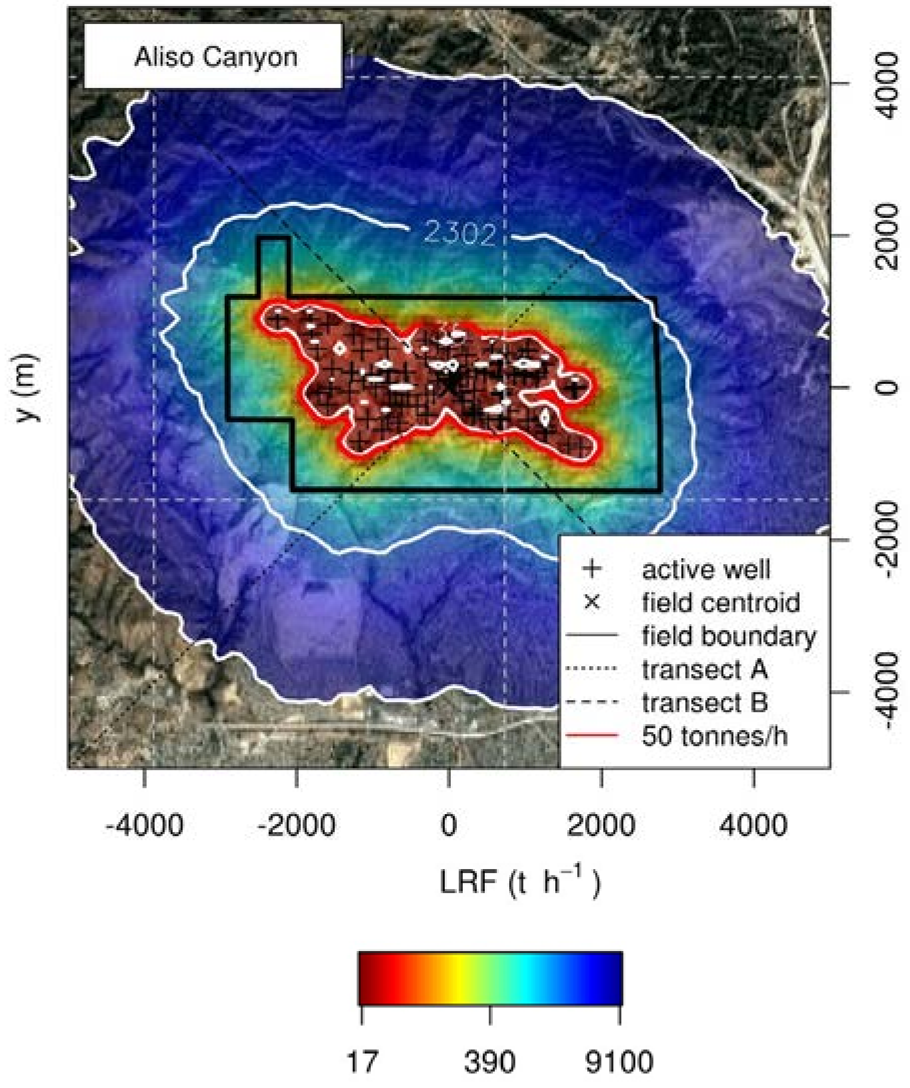
- We simulated dispersion of gas assuming major leak was occurring
- Concentrations decline rapidly with distance from a leakage source



La Goleta site showing high-population-density areas could experience high concentrations from leakage incidents.

Flammability is mostly an on-site hazard

- Fire and explosion are major hazards at UGS facilities
- Leakage rates and dispersion modeling can be combined to estimate the extent of the hazard zone
- Models suggest that flammable gas could extend to the edge of the red contour for leakage rate of 50 t/hr
- For reference, SS-25 well leaked at a rate of 20 t/hr prior to stopping



Risk includes likelihood AND consequences

- Risk is a measure of how likely an incident is combined with its severity

- Hazards are threats, i.e., what can potentially happen or go wrong

- Failure scenarios, or accident sequences, involve hazards playing out to cause actual consequences

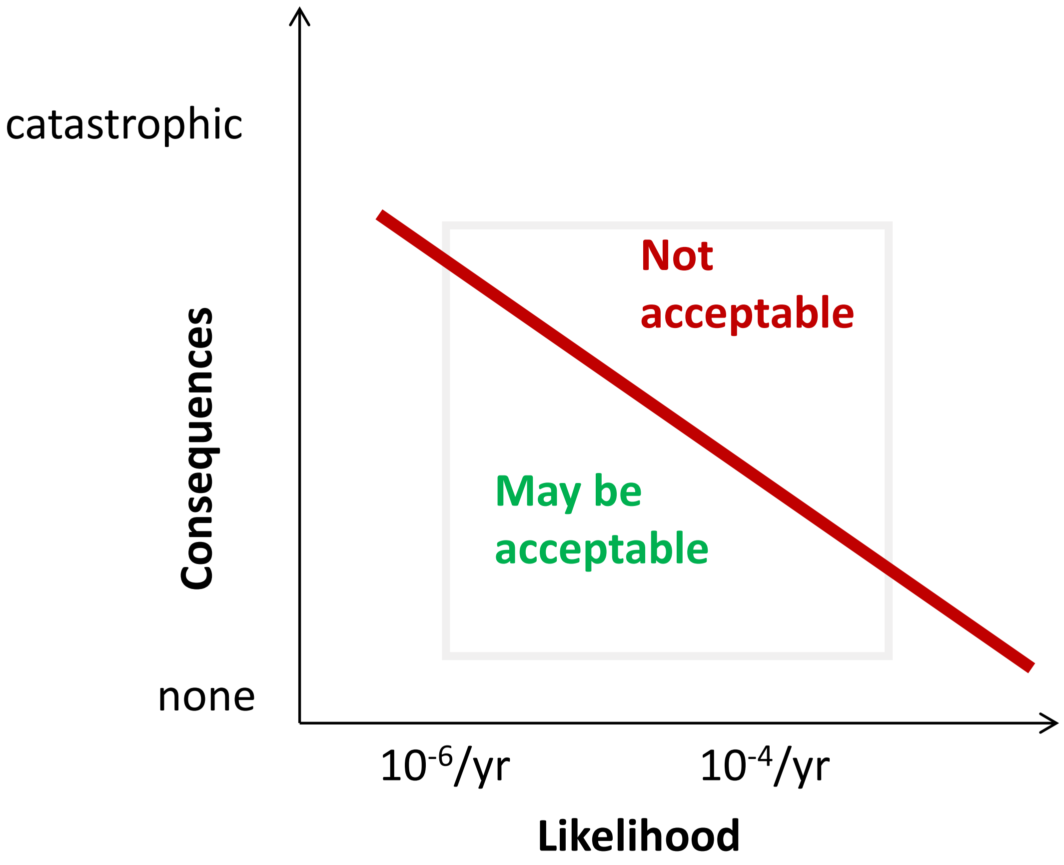


Table 7.1-1 does not show risk

- Table 7.1 shows salient characteristics of UGS sites in California related to the various aspects of UGS risk, e.g.,
  - How much gas is stored?
  - How old are the wells?
  - What is surrounding the site?

- The table shows does not show risk or how or whether risks are being managed through *prevention* or *mitigation*

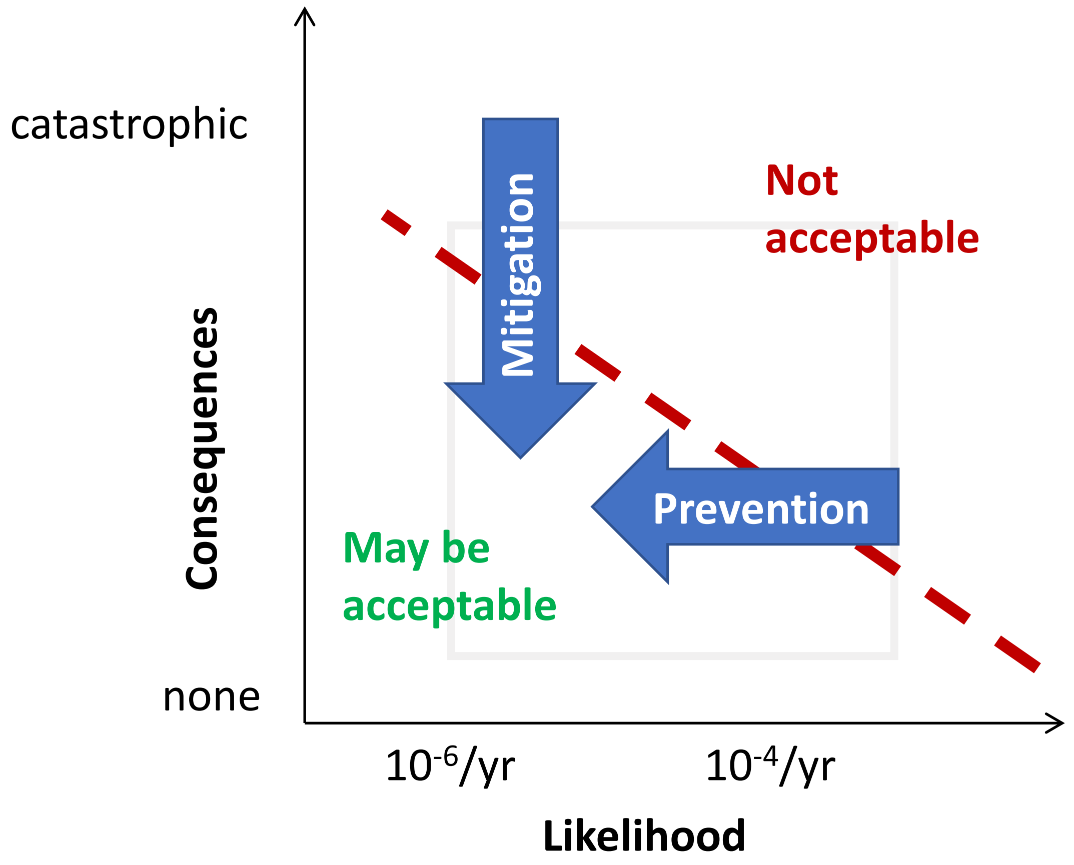


Table 7.1 shows aspects of UGS sites that are important in risk assessment

- Rows 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
  - independent facilities
  - northern California utility-owned facilities
  - southern California facilities listed
- Darker shading generally corresponds to larger expected hazard
- Does not take into account any and all risk mitigation actions.
  - (risk mitigation can be prevention and/or consequence mitigation)

Risk-Related Characteristics

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	Facility[1]	Independents					Pacific Gas and Electric			Southern California Gas			
		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
Health and safety	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)	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)	3,038 (5,772)
GHG emissions	Average observed methane emission rate (kg CH4/hr)	88	37	0	43	35	11	150	16	200[3]	740	36	0
	Extrapolated annual emissions/average annual gas injection (%)	0.8	0.4	0.0	0.4	0.1	0.1	0.2	0.4	0.2[3]	1.2	0.1	0.0

[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]Aliso emissions measured following repair of the 2015 blowout

	Facility[1]	Independents			
		Gill Ranch Gas	Kirby Hill Gas	Lodi Gas	Princeton Gas
UGS facility characteristics	2015 Capacity (Bcf)	20.0	15.0	17.0	11.0
	Average depth (range) of storage reservoir(s) (ft)	5,850 - 6,216	1,550 - 5,400	2,280 - 2,515	2,170
	Average annual gas transfer per well per from 2006 to 2015 (million scf)	150	69	511	78
	Number of open[2] wells connected to storage reservoir in 2015	12	18	26	13
	Median age of open[2] wells as of 2015 (yrs)	5	7	13	4

Risk-Related Characteristics

	Facility[1]	Independents					Pacific Gas and Electric			Southern California Gas			
		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										00	3,950	6,200
	Average a to 2015 (										4	232	13
	Number reservoir											18	54
	Median a											63	79
Failure modes, likelihoods, and hazards	Maximum											X	X
	Last fault flow line(										00*	<130,000*	None
	Hazard of present										ely	Unlikely	No
	Max. 2% accelerat										5	2.65	1.65
	Earthqua											?	Yes
	Tsunami											Yes	?
	Flooding											Yes	No
	Fire haza (maximum										igh	Not zoned	Very high
	Number (2008) an											0	3
Health and safety	Proximity (km)											0.5	0.0
	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)	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)	3,038 (5,772)
GHG emissions	Average observed methane emission rate (kg CH4/hr)	88	37	0	43	35	11	150	16	200[3]	740	36	0
	Extrapolated annual emissions/average annual gas injection (%)	0.8	0.4	0.0	0.4	0.1	0.1	0.2	0.4	0.2[3]	1.2	0.1	0.0

[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]Aliso emissions measured following repair of the 2015 blowout

Failure modes, likelihoods, and hazards	Maximum deep-seated landslide susceptibility	0	VII	0	0
	Last fault rupture through or (*) within 500 m of flow line(s) (yrs ago)	None	<130,000	None	None
	Hazard of Quaternary fault shearing of well(s) present	No	Yes	No	No
	Max. 2% probability of exceeding 0.2-sec spectral acceleration in 50 years (g)	1.45	1.55	1.25	0.95
	Earthquake-induced landslide hazard zone	No	?	No	No
	Tsunami hazard	No	No	No	No
	Flooding hazard	Yes	Yes	Yes	Yes
	Fire hazard severity zones - predominant (maximum, if different)	Not zoned (moderate)	Moderate	Not zoned (moderate)	Not zoned (moderate)
	Number of reported distinct LOC incidents in Evans (2008) and in Folga et al. (2016)	0	0	0	0

Risk-Related Characteristics

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	Facility[1]	Independents					Pacific Gas and Electric			Southern California Gas			
		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
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	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	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 open[2] wells connected to storage reservoir in 2015	12	18	26	13	17	21	88	7	115	41	18	54
	Median age of open[2] wells as of 2015 (yrs)	5	7	13	4	7	36	41	41	42	39	63	79
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 accelerat…	1.45	1.55	1.25	0.95	0.65	2.15	1.25	1.85	2.75	2.45	2.65	1.65
	Earthqua…											?	Yes
	Tsunami											Yes	?
	Flooding											Yes	No
	Fire hazar… (maximum…										…igh	Not zoned	Very high
	Number o… (2008) an…											0	3
Health and safety	Proximity… (km)											0.5	0.0
	Populatio…										…59	101,371	691,757
	Median (… 2015, pre…										…75 (…96)	2,197 (3,456)	3,038 (5,772)
GHG emissions	Average … CH4/hr)											36	0
	Extrapolated annual emissions/average annual gas injection (%)	0.8	0.4	0.0	0.4	0.1	0.1	0.2	0.4	0.2[3]	1.2	0.1	0.0

[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]Aliso emissions measured following repair of the 2015 blowout

Health and safety	Proximity of handling plant (center) to well field (km)	0.0	0.7	6.5	0.9
	Population in proximity to UGS	909	401	23,771	848
	Median (max) formaldehyde emissions from 1996 - 2015, predominantly from compressors (lbs/yr)	4 (5)	108 (205)	1,291 (1,291)	not reported
GHG emissions	Average observed methane emission rate (kg CH4/hr)	88	37	0	43
	Extrapolated annual emissions/average annual gas injection (%)	0.8	0.4	0.0	0.4

	Facility[1]	Pacific Gas and Electric			Southern California Gas			
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UGS facility characteristics	2015 Capacity (Bcf)	17.9	82.0	2.3	86.2	27.0	19.7	2.4
	Average depth (range) of storage reservoir(s) (ft)	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)	255	75	22	197	244	232	13
	Number of open[2] wells connected to storage reservoir in 2015	21	88	7	115	41	18	54
	Median age of open[2] wells as of 2015 (yrs)	36	41	41	42	39	63	79
Failure modes, likelihoods, and hazards	Maximum deep-seated landslide susceptibility	VI	0	VII	X	X	X	X
	Last fault rupture through or (*) within 500 m of flow line(s) (yrs ago)	<130,000*	None	None	<15,000*	<15,000*	<130,000*	None
	Hazard of Quaternary fault shearing of well(s) present	Maybe	No	No	Yes	Unlikely	Unlikely	No
	Max. 2% probability of exceeding 0.2-sec spectral acceleration in 50 years (g)	2.15	1.25	1.85	2.75	2.45	2.65	1.65
	Earthquake-induced landslide hazard zone	?	No	No	Yes	Yes	?	Yes
	Tsunami hazard	No	No	No	No	No	Yes	?
	Flooding hazard	No	Yes	No	No	No	Yes	No
	Fire hazard severity zones - predominant (maximum, if different)	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)	1	2	1	3	1	0	3
Health and safety	Proximity of handling plant (center) to well field (km)	0.3	0.0	0.4	0.2	0.0	0.5	0.0
	Population in proximity to UGS	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)	4,968 (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)	11	150	16	200[3]	740	36	0
	Extrapolated annual emissions/average annual gas injection (%)	0.1	0.2	0.4	0.2[3]	1.2	0.1	0.0

Notes

Montebello facility

- Officially closed December 31, 2016 following extensive surface leakage of natural gas
- Included in table because it apparently operated for some periods during our 10-year study period January 1, 2006 to December 31, 2015.

Some risk-related characteristics are also benefits

- Storage volume
- Proximity to population correlates to proximity to emergency services

New regs require risk management

- Qualitative and quantitative risk assessment is now required
- Identifying, assessing, and prioritizing prevention & mitigation actions will lead to lower risk

New regs & risk management promise to improve UGS safety and reliability

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- UGS has been in a gray area between oil and gas production and energy distribution infrastructure
- New regulations will greatly improve UGS safety and reliability
  - No single-point failure well configurations
  - Mechanical integrity testing
  - Risk management plans (RMPs)
- Regulations now require
  - Quantitative risk assessment
  - Regular review and updating of RMPs
  - Assessment of human factors

Take Away Messages: Key Question 1

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Managing Risk

- Risks associated with underground gas storage can be managed and mitigated.
- The new draft regulations are a major step, have room for improvement, and should undergo regular review.
- Conduct methane monitoring for early identification of leaks.

Minimizing Impact

- Consider population proximity and density.
- Require information on gas composition and be ready for rapid monitoring and modeling of gas dispersion.

Facility-by-Facility Evaluation

- A few facilities have relatively higher risk than others in California.
- Quantifying risks for each facility allows examining tradeoff between risk and benefits of individual facilities.

Questions?

Key Question 1

What risks do California's underground gas storage facilities pose to health, safety, environment and infrastructure?

Focus of Talk:

Human Health Hazards, Risks, and Impacts Associated with Underground Gas Storage in California

Seth B.C. Shonkoff, PhD, MPH

PSE Healthy Energy / UC Berkeley / Lawrence Berkeley National Lab

Co-Authors & Contributors

Chapter 1: Section 1.4

Human health hazards, risks, and impacts associated with underground gas storage in California

Seth B.C. Shonkoff, PhD, MPH
PSE Healthy Energy, UC Berkeley, LBNL

Lee Ann Hill, MPH
PSE Healthy Energy

Eliza D. Czolowski, MPS
PSE Healthy Energy

Kuldeep Prasad, PhD
National Institute of Standards and Technology

S. Katharine Hammond, PhD
University of California, Berkeley

Thomas E. McKone
University of California, Berkeley
Lawrence Berkeley National Lab

Overview of Talk

- Study Goals & Health Assessment Approach
  - Toxic Air Pollutant Assessment
  - Proximity Analysis
  - 2015-2016 Aliso Canyon SS-25 Well Blowout
  - Occupational Health and Safety
- Key Findings & Recommendations

Health Assessment: Key Findings

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1. There are a number of human health hazards associated with UGS in California that are **predominantly attributable to exposure to toxic air pollutants and gas-fueled fires or explosions during large LOC events**.
   - However, many UGS facilities also emit multiple health-damaging air pollutants during **routine operations** — formaldehyde in particular, which is of concern for the health of workers and nearby communities.
2. **Large LOC events (e.g., the 2015 Aliso Canyon incident) can clearly cause health symptoms and impacts in nearby populations** and are a key challenge for risk management efforts.
3. **There is uncertainty with respect to some of the *mechanisms* of human health harm related to the 2015 Aliso Canyon incident and other UGS LOC events in the future. This is mostly attributable to the lack of access to data on the composition of stored gas in the facilities and limitations of air quality and environmental monitoring during and after these events.** While our research team attempted repeatedly to obtain the relevant gas composition data, we were unsuccessful.

Health Assessment: Key Findings, Cont…

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4. UGS facilities located in areas of **high population density and in close proximity to populations are more likely to cause larger population morbidity** attributable to exposures to substances emitted to the air than facilities in areas of low population density or further away populations.
5. During large LOC events, if emitted gases are ignited, the **explosion hazard zone at UGS facilities can extend beyond the geographic extent of the facility**, creating flammability hazards to nearby populations.
6. **Workers on site are likely exposed to higher concentrations of toxic chemicals during both routine and off-normal operations**, and workers on site have greater chance of exposure to fire or explosions during LOC events.
7. **California-specific as well as other peer-reviewed studies relevant to California on human health hazards associated with UGS facilities are scarce.**

Health Assessment Approach

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1. Analysis of **toxic air pollutant emission data** reported to regional air districts and to the State (CA Hotspots Program)
2. **Proximity analysis of populations near UGS facilities** and their potential exposure to toxic air pollutants and natural gas fires and explosions using numbers, density, and demographics of people in proximity to UGS facilities and air dispersion modeling
3. Assessment of air quality and human health impact datasets collected during the **2015 Aliso Canyon incident**
4. Assessment of **occupational health and safety hazards** associated with Aliso Canyon and UGS facilities in general

While Our Research Team Attempted Repeatedly To Obtain The Relevant Gas Composition Data We Were Unsuccessful

Appendix 1.E. Efforts to Seek Information on Stored Gas Composition

In order to better assess the inventory of chemicals available for release from storage wells during a loss-of-containment (LOC) event, the health impacts team worked with the CCST and the CPUC to make a formal request to each of the storage facility operators for information on stored-gas composition. Contained in this Appendix are (1) a copy of the letter of request we sent out along with (2) the letters of response we received from Southern California Gas (operator of Aliso Canyon, Honor Rancho, La Goleta Gas, Montebello, and Playa del Ray), PG&E (operator of McDonald Island Gas, Los Medanos Gas, Pleasant Creek Gas), Rockport Gas Storage Partners (operator of Kirby Hills, Lodi Gas, and Wild Goose Gas), Central Valley Gas (operator of Princeton Gas), and Gill Ranch LLC (operator of Gill Ranch Gas). As an introduction to these attached materials, we discuss here briefly what we requested and what we got back.

Information we were seeking

As part of the health risk assessment and based on emissions reported and detected from the Aliso Canyon event, we compiled a table of priority chemicals (attached to our request letter below) that we determined would be in the stored gas at trace levels but relevant to public health. Our concern is that these trace constituents could come out with the natural gas during a LOC and might lead to exposures on-site (occupational) or to the nearest off-site community that could exceed health-protection guidelines. But the only way to make this determination is by having knowledge of concentrations of these priority chemicals in the stored gas.

In order to obtain this information, we asked first of the operators: "Please show the proportion of each chemical in parts per billion that is present in the gas after a standard operational withdrawal prior to any processing...." We followed this with a question about detection limits for assessing trace concentrations. If the operator could not fully address the first two questions, we included a third questions that asked why they were not monitoring for these chemicals, what are the barriers to more extensive monitoring, and what would it take to make feasible the monitoring of these chemicals

The responses we received

Although we received responses from all of the operators in California, their responses revealed an absence of both the information we requested and the ability to obtain this information in a timely manner. Some of the responses were terse and somewhat incomplete, others were more detailed but still failed to provide new insight about the current inventory of toxic air contaminants in stored natural gas. In reviewing the responses, it is clear that all of the operators are only currently monitoring for the quality of the gas and the presence of sulfur compounds. None measure for other toxic air contaminants. The operators had different responses with regard to the barriers to more extensive monitoring, and what it would take to make feasible the monitoring of these chemicals. Some indicated

- **Appendix 1.E (Chapter 1, p. 461)** details our request to UGS operators.
- We received feedback from each facility (Appendix 1.F), but were not provided useful data needed to draw meaningful conclusions about chemical composition.
- **These data are essential to assess health risks posed by UGS.**

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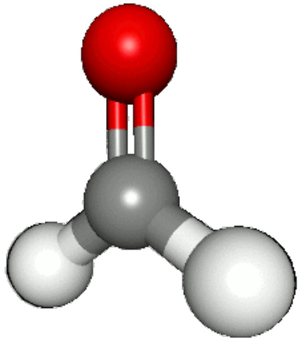
Toxic Air Pollutants Associated with UGS



- **Stored Gas:** Toxic compounds are admixed with stored natural gas in depleted oil and gas reservoirs and are emitted from leaks and LOC events.
- **Aboveground infrastructure**: compressor stations and other equipment emit health-damaging air pollutants (e.g., formaldehyde) into the ambient air during normal and off-normal operations.

Approach to Toxic Air Pollutant Assessment:

- Quantify pollutants reported as historically emitted from California UGS facilities (CA Hotspots Program)
- Assess acute and chronic toxicity for non-cancer and cancer endpoints
- Rank the hazard of chemicals known to be emitted from UGS facilities by annual mass emitted and chemical-specific toxicity for future monitoring and risk assessment considerations.

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California Emissions Inventories

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Toxic air pollutant data availability for CA UGS facilities

YEAR	FACILITY NAME: Aliso Canyon	Princeton Gas	Gill Ranch	Goleta	Honor Rancho	Lodi Gas	Kirby Hill	Los Medanos	McDonald Island	Montebello	Playa del Rey	Pleasant Creek	Wild Goose
2016	SCAQMD				SCAQMD					SCAQMD	SCAQMD		
2015	SCAQMD	CARB	CARB	CARB		CARB			CARB				CARB
2014		CARB	CARB	CARB		CARB	CARB	CARB	CARB				CARB
2013		CARB	CARB	CARB		CARB	CARB	CARB	CARB				CARB
2012		CARB	CARB	CARB		CARB	CARB	CARB	CARB				CARB
2011				CARB		CARB	CARB	CARB	CARB				CARB
2010				CARB		CARB	CARB	CARB	CARB				CARB
2009				CARB		CARB	CARB	CARB	CARB				CARB
2008				CARB		CARB	CARB	CARB	CARB				CARB
2007				CARB		CARB		CARB	CARB				CARB
2006				CARB		CARB		CARB	CARB				CARB
2005								CARB	CARB				CARB
2004								CARB					CARB
2003								CARB					
2002								CARB					
2001				CARB				CARB					
2000				CARB				CARB			CARB		
1999	CARB			CARB	CARB			CARB		CARB	CARB		
1998	CARB			CARB	CARB			CARB		CARB	CARB		
1997	CARB			CARB	CARB			CARB		CARB	CARB		
1996	CARB			CARB	CARB			CARB		CARB	CARB		

Data available – CARB or SCAQMD
Data available – CARB and SCAQMD
No data available
Site not in operation

- UGS facility-specific emissions data available from SCAQMD and CARB
- Data availability vary by facility and year
- Report emissions of criteria pollutants (tons/year) and toxic air pollutants (pounds/year)
- Emission inventories reportedly include routine operations and off-normal events
- **NOTE:** Emissions reporting lack spatial and temporal information required for formal risk assessment (emissions rates, location, equipment type, etc.).

Toxicity Ranking to Prioritize Compounds

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1 - Acute toxicant
2 - Chronic toxicant
3 - Carcinogen

*Gas-fired compressors are significant contributors to aboveground **formaldehyde** emissions associated with UGS.*

*NOTE: important compounds associated with UGS (e.g. **mercaptans**) are absent from emissions inventories*

Table 1.4-6. Chronic (noncancer and cancer) toxicity-weighted emissions from UGS facilities in California between 1987 and 2015. Compounds are listed by most hazardous to least hazardous based on chemical-specific median annual emissions and toxicity weights.

			Inhalation Toxicity Score		
	Chemical Name[1,2]	**CASRN**	**Median annual emissions (pounds/year)**	**Toxicity Weights**	**Toxicity-weighted emissions**
1,2,3	**Formaldehyde**	50-00-0	3159	46,000	145,310,537
1,2	**Acrolein**	107-02-8	206	180,000	37,066,065
2	**Ethylene dibromide**	106-93-4	4	2,100,000	8,428,974
1,2,3	**1,3-Butadiene**	106-99-0	57	110,000	6,236,313
1,2,3	**Benzene**	71-43-2	171	28,000	4,791,412
2	**2-Methyl naphthalene[1]**	91-57-6	6	710,000	4,433,950
1,2,3	**Acetaldehyde**	75-07-0	392	7,900	3,093,610
2	**Phenanthrene[1]**	85-01-8	2	710,000	1,388,760
2	**Tetrachloroethane**	79-34-5	4	210,000	760,790
2	**Trichloroethylene**	79-01-6	44	15,000	657,075

Proximity to UGS Facilities in CA

- We evaluated population proximity and population density near UGS facilities in California.
  - Residents, children and the elderly
  - Day care centers, hospitals, schools, and elderly care facilities
  - 0m – 8,000m (~5 mi) from each UGS facility
- We also used meteorological data to assess dispersion patterns of emissions from UGS facilities.

UGS facilities located in areas of high population density and in close proximity to populations are more likely to cause larger population morbidity from air pollutants and explosions

Populations in closest proximity to (**within**) UGS Facilities

Table 1.4-10. Population counts for the 0 m buffer, by underground storage site.

Underground Storage Facility	Number of Residents	Under Age 5	Age 75 and Older
Playa del Rey	3,782	165	193
Montebello	1,470	75	149
Lodi	242	12	9
La Goleta	39	1	3
Aliso Canyon	25	1	2
McDonald Island	24	4	0
Princeton	3	0	0
TOTAL	**5,885**	**258**	**356**

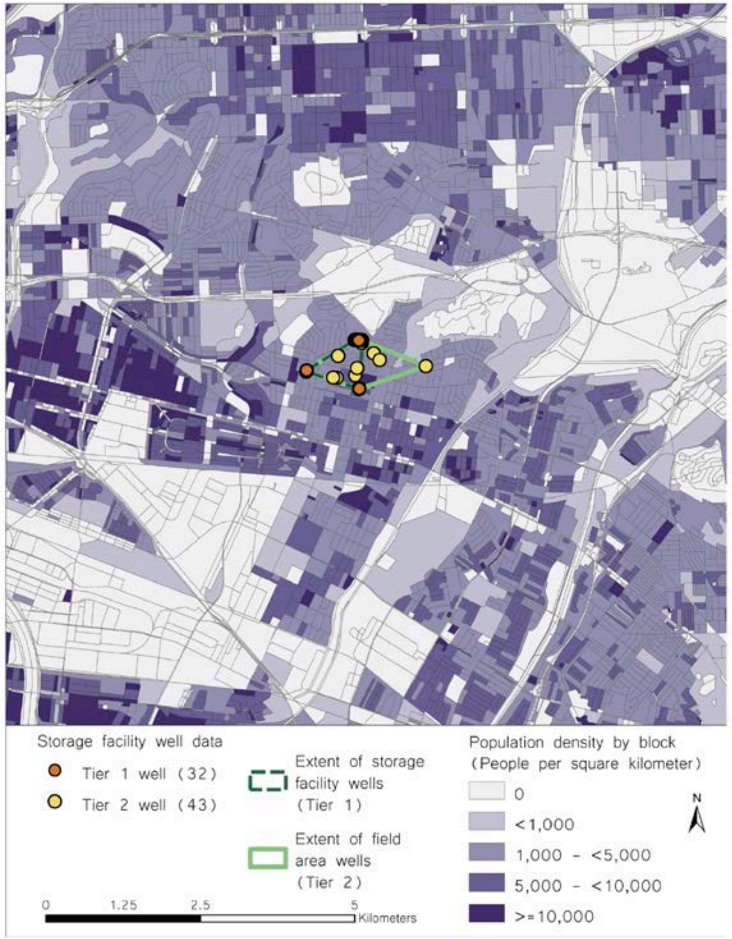

Figure 1.4-4. Population density measured in people per square kilometer around the Montebello UGS facility.

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Statewide Proximity to UGS, including vulnerable populations

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Table 1.4-8. Summed population and sensitive receptor counts in proximity to underground storage sites in California, by buffer distance.

Distance From any UGS Well (meters)	Number of Residents	Under 5	Age 75 and Older	Number of Open Schools	Number of Children Enrolled in School	Number of Open Daycare Centers	Number of Open Elderly Care Facilities	Number of Hospitals
0	5,585	257	356	0	0	1	0	0
100	8,179	408	542	0	0	1	0	0
200	11,443	568	788	3	1,046	5	1	0
400	18,385	876	1,434	4	1,448	7	2	0
600	28,158	1,308	2,058	9	3,699	18	2	0
800 (1/2 mile)	40,503	1,843	2,704	12	5,435	29	2	0
1,000	54,127	2,597	3,458	17	9,974	35	2	1
1,600 (1 mile)	113,721	5,522	6,278	32	23,035	64	3	2
2,000	161,367	8,051	8,467	42	28,868	89	3	3
5,000	743,678	42,543	43,323	213	117,406	516	109	8
8,000	1,864,775	115,124	103,085	556	292,935	1,337	326	23

Distances were determined using concentric, circular buffers

Emission Dispersion & Population Density

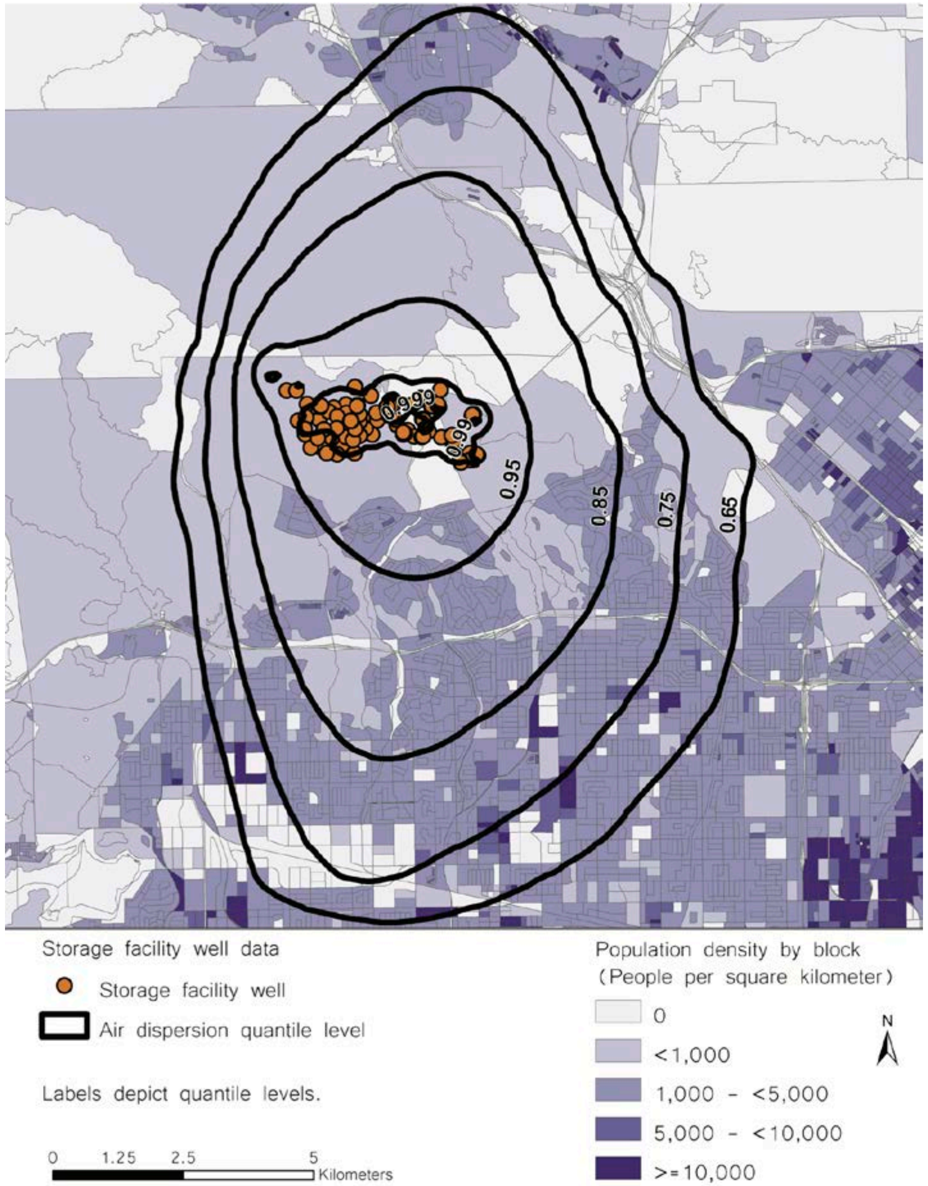
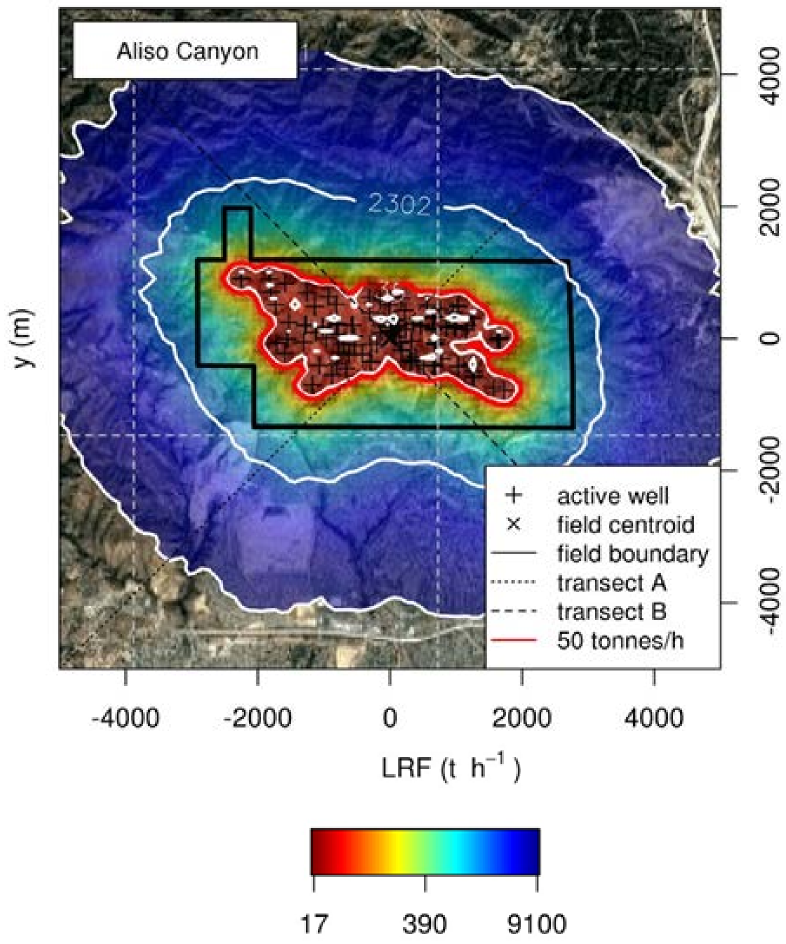


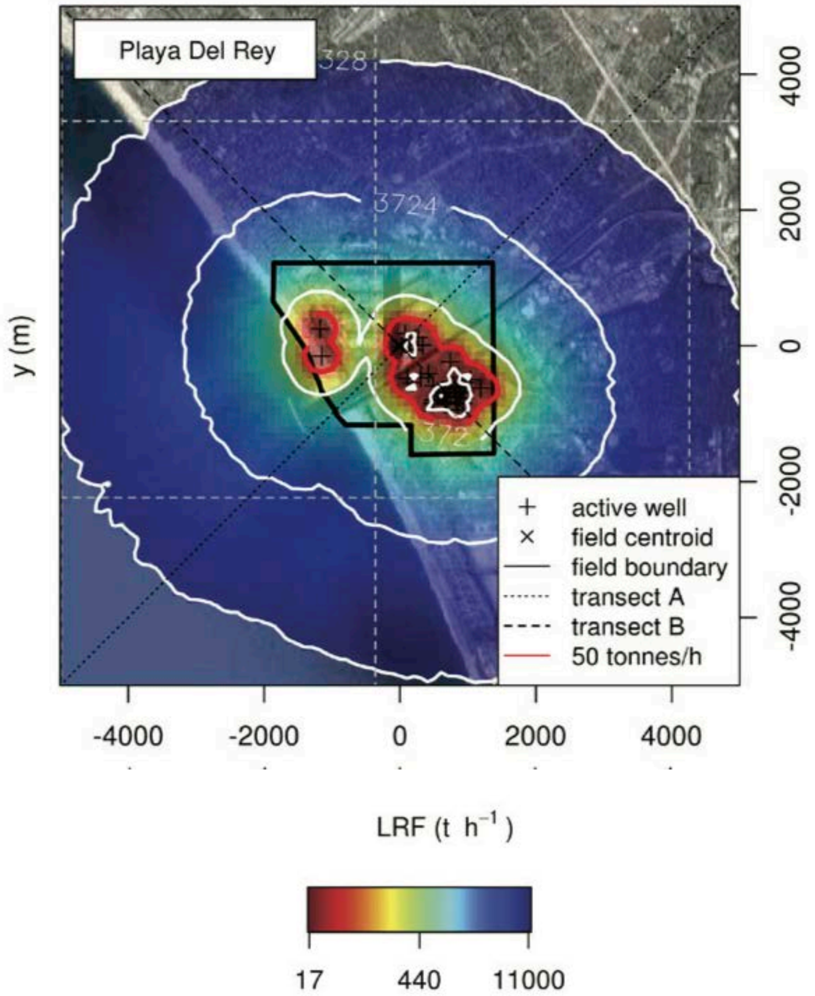
Figure 1.4-13. Air dispersion quantiles and population density at the Aliso Canyon UGS facility.

- We used estimated facility-specific meteorological data for refined assessment of populations that may be most likely to be exposed to UGS emissions

During large LOC events, if emitted gases are ignited, the explosion hazard zone at UGS facilities can extend beyond the geographic extent of the facility, creating flammability hazards to nearby populations.



Facilities where well pads are located at the boundary of the facility (e.g., Playa Del Rey) would result in potential hazard zones that extend outside the facility.



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Aliso Canyon Incident

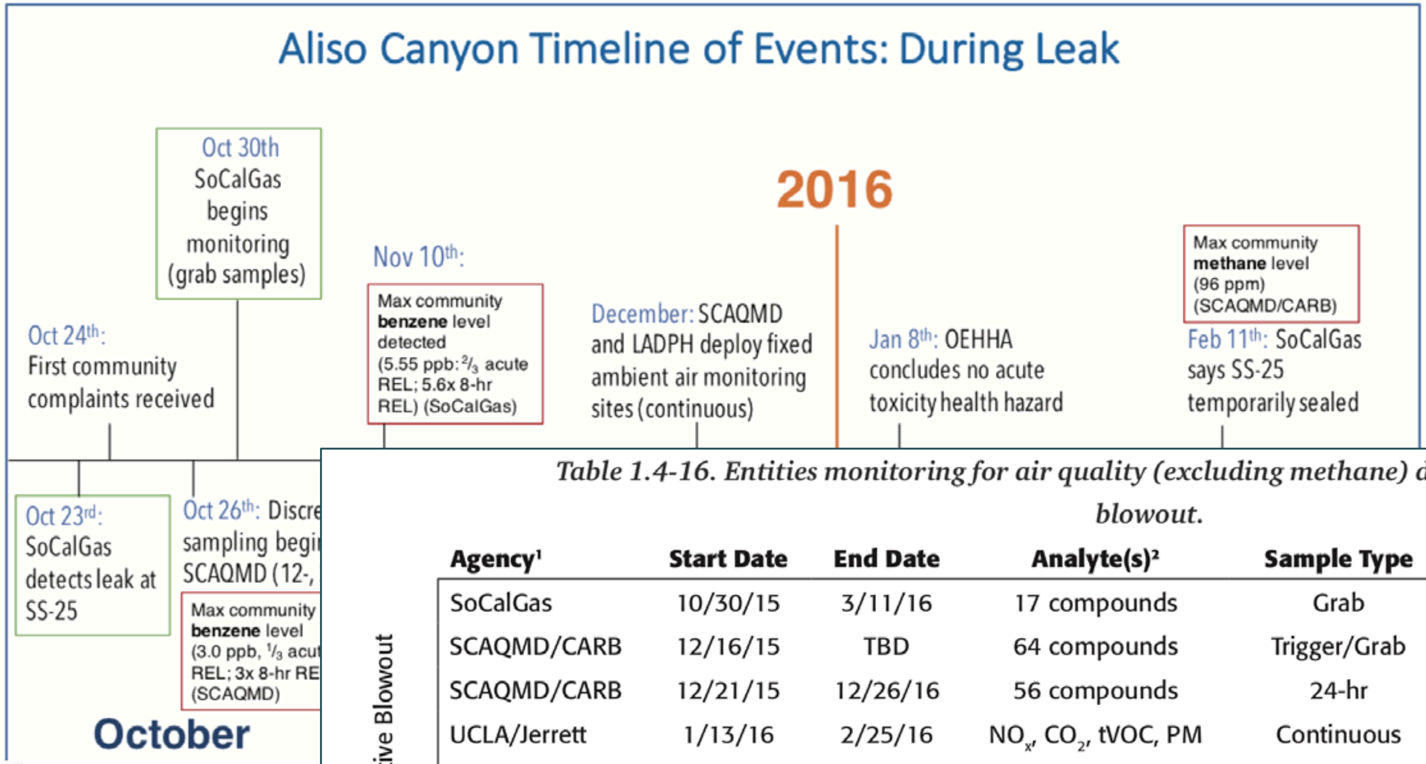

Table 1.4-16. Entities monitoring for air quality (excluding methane) during and after the SS-25 blowout.

	Agency[1]	Start Date	End Date	Analyte(s)[2]	Sample Type	# Sites	Location
During Active Blowout	SoCalGas	10/30/15	3/11/16	17 compounds	Grab	38	Porter Ranch/SS-25
	SCAQMD/CARB	12/16/15	TBD	64 compounds	Trigger/Grab	2	Porter Ranch
	SCAQMD/CARB	12/21/15	12/26/16	56 compounds	24-hr	4	Porter Ranch/Reseda
	UCLA/Jerrett	1/13/16	2/25/16	NO_x, CO_2, tVOC, PM	Continuous	6	Porter Ranch/Northridge
	UCLA/Jerrett	1/13/16	2/12/16	25 VOCs	Passive Sampler	24	Porter Ranch/Northridge
	CARB	1/14/16	7/21/16	Benzene	Hourly	1	Site 5 (34.294993, -118.558115)
	SoCalGas	1/11/16	2/3/16	17 compounds	12-hr	13	Porter Ranch/SS-25
	SCAQMD	2/2/16	7/19/16	Benzene	Hourly	1	Site 7 (34.26140, -118.594)
Post-Active Blowout	SCAQMD/CARB	2/26/16	2/24/17	H_2S	Hourly	1	Site 3 (34.293563, -118.580401)
	LACDPH	3/25/16	4/6/16	250 compounds	24-hr (summa)	210	Porter Ranch/Northridge
	LACDPH	3/25/16	4/8/16	86 compounds	Wipe	210	Porter Ranch/Northridge
	LACDPH	4/20/16	4/20/16	187 compounds	Soil	5	SS-25

1 SCAQMD – South Coast Air Quality Management District; CARB – California Air Resources Board; UCLA/Jerrett – University of California, Los Angeles – Michael Jerrett; LACDPH – Los Angeles County Department of Public Health

2 NO_x – nitrogen oxides; CO_2 – carbon dioxide, tVOC – total volatile organic compounds, PM – particulate matter; VOC – volatile organic compounds; H_2S – hydrogen sulfide

Air and Environmental Monitoring Was Extensive But Insufficient

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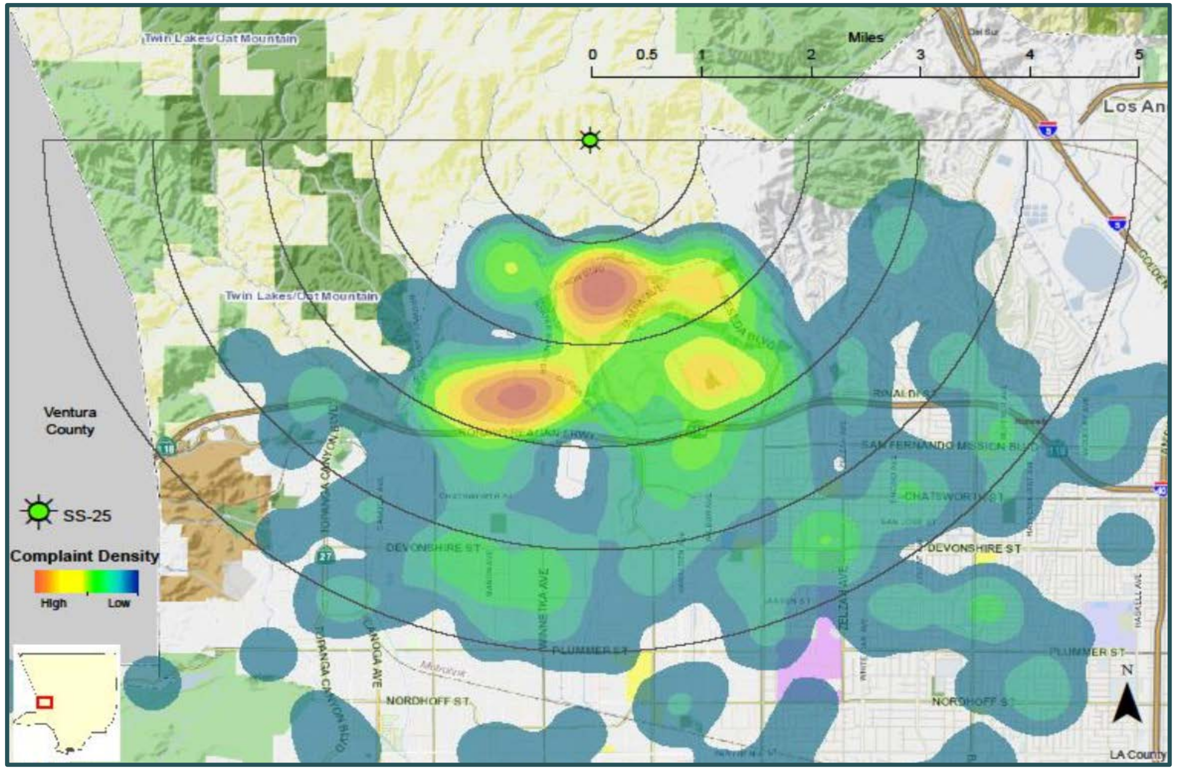
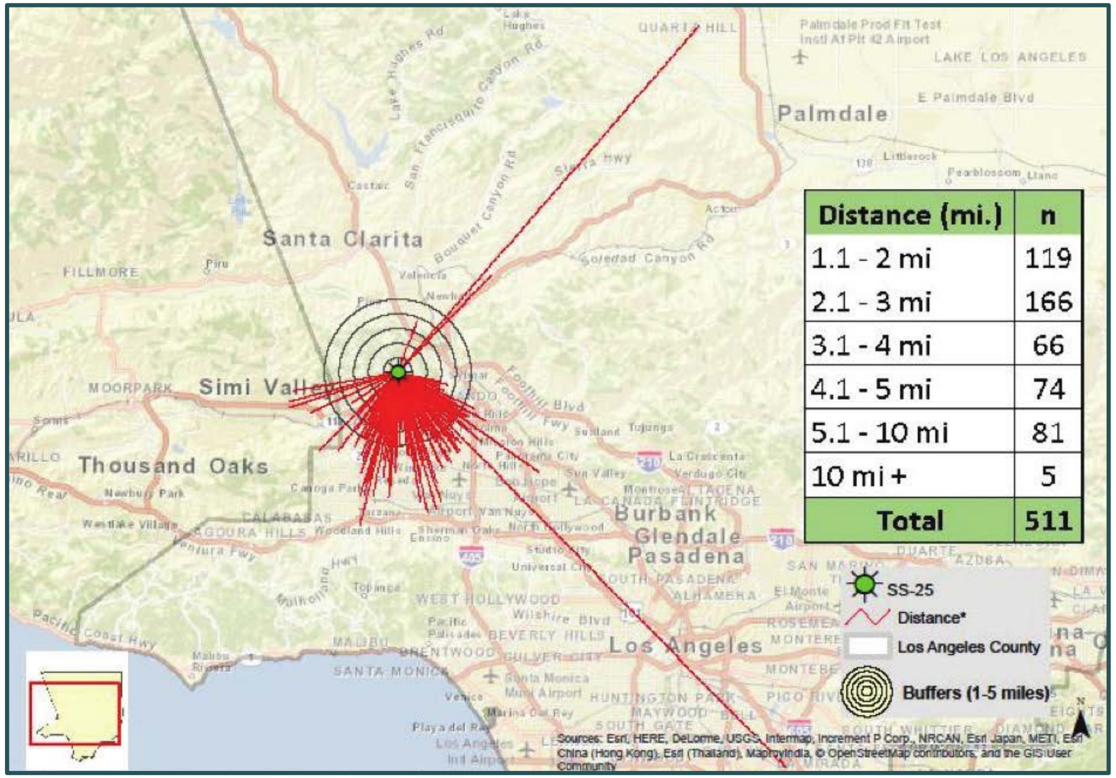
- All air quality monitoring **missed the first few days of the blowout**, where exposures to the highest concentrations likely occurred
- **No continuous health-damaging air pollutant monitoring until well after the peak of emissions**
- **Only 21 (36%) of chemicals reportedly emitted from Aliso Canyon** (according to emission inventories) were monitored for during or after the 2015 Aliso Canyon incident in ambient air
- Compounds that were monitored for were often monitored at **limits of detection above health-relevant thresholds**

Effective health risk management requires continuous, rapid, reliable, and sensitive (low-detection limit) environmental monitoring of chemicals of concern in both ambient and indoor environment.

Large LOC events can cause health symptoms and impacts in the nearby population



Health complaint density



Distance (mi.)	n
1.1 - 2 mi	119
2.1 - 3 mi	166
3.1 - 4 mi	66
4.1 - 5 mi	74
5.1 - 10 mi	81
10 mi +	5
Total	511

Complaint distance from SS-25

LACDPH (2016c)

Reported Symptoms During and After Leaks in Population Nearby Aliso Canyon

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	During active gas leak			After well was sealed		
	Number of households (n=210)	Projected number of households (n=7,755)	Weighted % of households (95% CI)	Number of households (n=210)	Projected number of households (n=7,755)	Weighted % of households (95% CI)
Any symptom(s)	170	6,278	81.3 (75.5 – 87.2)	130	4,801	62.5 (56.3 – 68.7)
Eye, nose and/or throat irritation	153	5,650	73.9 (67.2 – 80.6)	123	4,542	59.1 (52.6 – 65.7)
Headache/migraine	148	5,465	71.8 (65.3 – 78.4)	108	3,988	51.9 (45.0 – 58.9)
Respiratory complaint*	138	5,096	67.0 (60.6 – 73.3)	105	3,878	50.7 (44.1 – 57.4)
Stress	123	4,542	60.0 (52.4 – 67.6)	88	3,250	42.9 (36.1 – 49.8)
Dizziness/light headedness	121	4,468	59.9 (53.1 – 66.7)	81	2,991	39.9 (33.5 – 46.3)
Nausea/vomiting	112	4,136	54.4 (48.2 – 60.5)	83	3,065	40.7 (34.3 – 47.0)
Nosebleed(s)	97	3,582	46.9 (40.2 – 53.6)	64	2,363	30.9 (24.4 – 37.4)
Skin rash/irritated skin	95	3,508	46.1 (38.6 – 53.6)	76	2,807	37.3 (31.0 – 43.5)
Diarrhea	55	2,031	27.0 (21.1 – 32.8)	44	1,625	21.7 (15.5 – 27.8)
Fever	32	1,182	16.0 (10.7 – 21.3)	26	960	12.9 (8.7 – 17.1)

- While mechanisms of health symptoms are not all understood, it is clear that the majority of nearby residents experienced health symptoms during and after the Aliso Canyon LOC event.

LACDPH (2016e)

Occupational Health & Safety

Workers on site are exposed to higher concentrations of toxic chemicals during both routine and off-normal operations, and workers on site have greater chance of exposure to fire and explosions during LOC events.

- Hydrogen sulfide exposure is of key concern for workers, as it presents a toxic and flammability hazard at the work site
- Workers at some UGS facilities may live on site for periods of time, rendering occupational exposure values inappropriate.
- Workers require proper safety training – SoCalGas was cited by CA Division of Occupational Health and Safety for an insufficient trained incident commander at the Aliso Canyon facility
- UGS workers may not be adequately overseen by any agency

Not All UGS Facilities are Created Equal

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		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

Key Recommendations from Health Assessment

1. Require that the composition of gas withdrawn from the storage reservoir be disclosed, along with any chemical use on site that could be leaked, intentionally released, or entrained in gas or fluids during LOC events.
2. Require facility-specific meteorological (e.g., wind speed and direction) data-collection equipment be installed at all UGS facilities.
3. Require that monitoring approaches to air quality and human health be appropriately and rapidly implemented both during routine operations and during LOC events.
4. Require that steps be taken to decrease exposure of nearby populations to toxic air pollutants emitted from UGS facilities during routine operations and LOC incidents. These steps could include:
   - Increase application and enforcement of emission control technologies to limit air pollutant emissions
   - Replace gas-powered compressors with electric-powered compressors to decrease emissions of formaldehyde
   - Implement minimum-surface setbacks between UGS facilities and human populations.
5. Require that UGS workplaces conform to requirements of CalOSHA and federal OSHA (Occupational Safety and Health) to protect the health and safety of all on-site workers, regardless if operators are legally bound to comply.

Questions?

Seth B.C. Shonkoff, PhD, MPH

PSE Healthy Energy / UC Berkeley / LBNL

sshonkoff@psehealthyenergy.org

sshonkoff@berkeley.edu

@PhySciEng
www.psehealthyenergy.org

Questions?

Key Question 2

Does California need underground gas storage to provide for energy reliability in the near term (through 2020)?

Dr. Jane C.S. Long

Retired LLNL

Co-Chair, Steering Committee

Second Major Conclusion and Recommendation

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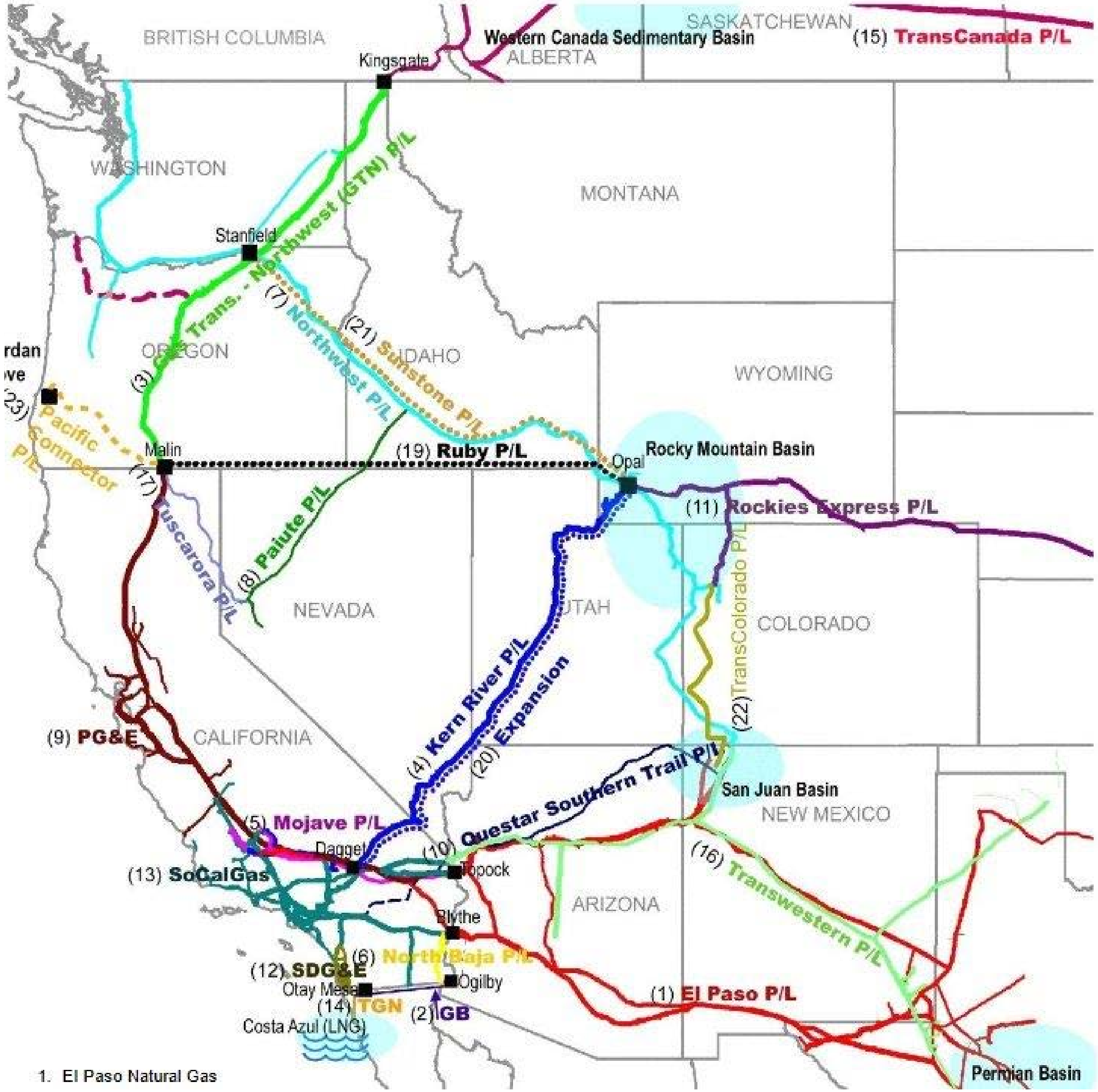
- **Conclusion ES-2:** California's energy system currently needs natural gas and underground storage to run reliably. Replacing underground gas storage in the next few decades would require very large investments to store or supply natural gas another way, and such new natural gas-related infrastructure 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.

Key Question 2   Sub-topics

- Current role of gas storage in California today
- Changes to the the role of gas storage
- Impacts of historical storage facility performance problems
- Requirements to replace gas storage while maintaining reliability
- Impacts from the new requirements/regulations on the reliability of gas supply



Western Gas Pipelines

Source: California Energy Commission

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California gas import capacity

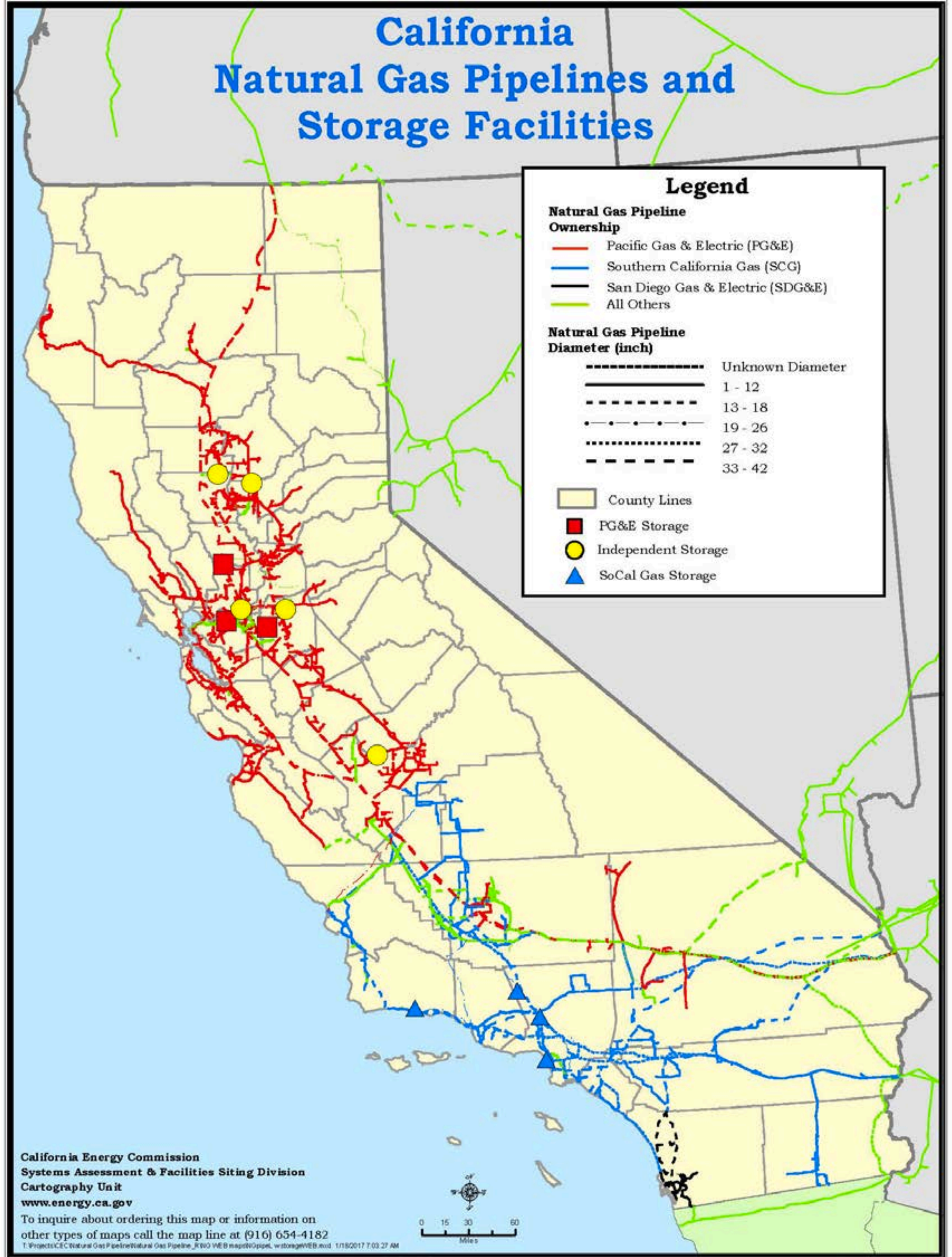
Import takeaway capacity:

PG&E: 2.9 bcfd

SoCalGas: 3.4 bcfd

CA production : 1.2 bcfd

TOTAL SUPPLY CAPACITY: 7.5 bcfd



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General Layout of California High Pressure Pipeline and Storage Facilities

Source: California Energy Commission

Underground Gas Storage Working Inventory

	Working Capacity (Bcf)	Maximum Withdrawal Capacity (Bcfd)
U.S.	4735.8	
California	375.5	
Utility-Owned & Controlled	237.5	4.8
PG&E	100.3	1.53
SoCalGas	135.4	3.66
Independently Owned	106.0	2.9
Gill Ranch	20	0.65
Lodi	29	0.80
Wild Goose	50	1.2
Central Valley	11	0.30

Source: EIA, U.S. Field Level Storage Data

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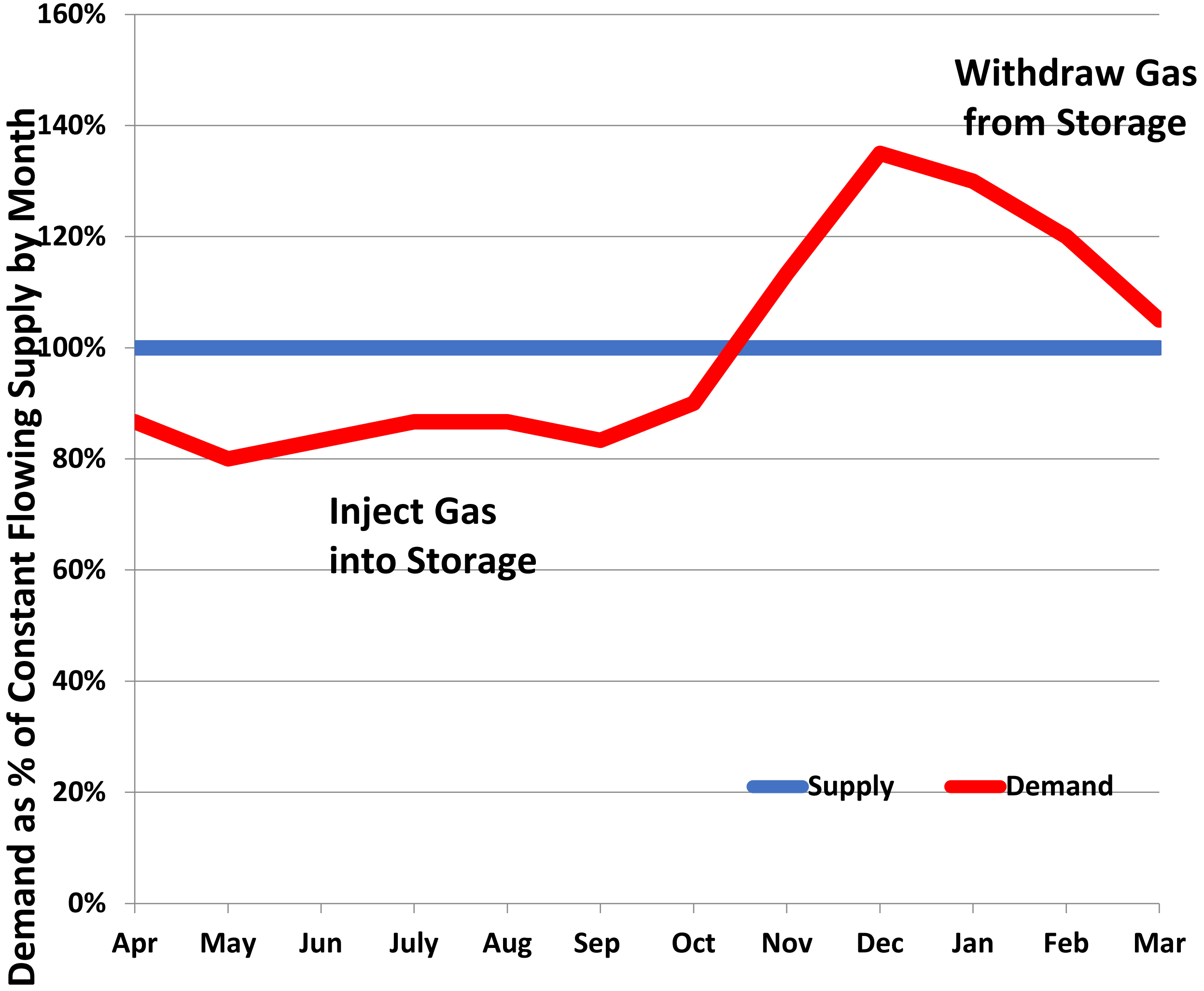
- What is underground gas storage used for? Why do we need it?

Gas storage functions



Source: Aspen Environmental Group

1. **Monthly Winter Demand**
   Provides supply when monthly winter needs exceed the available pipeline supply capacity.

2. Flat Production
   Provides supply when demand exceed supply production rate.

Gas storage functions

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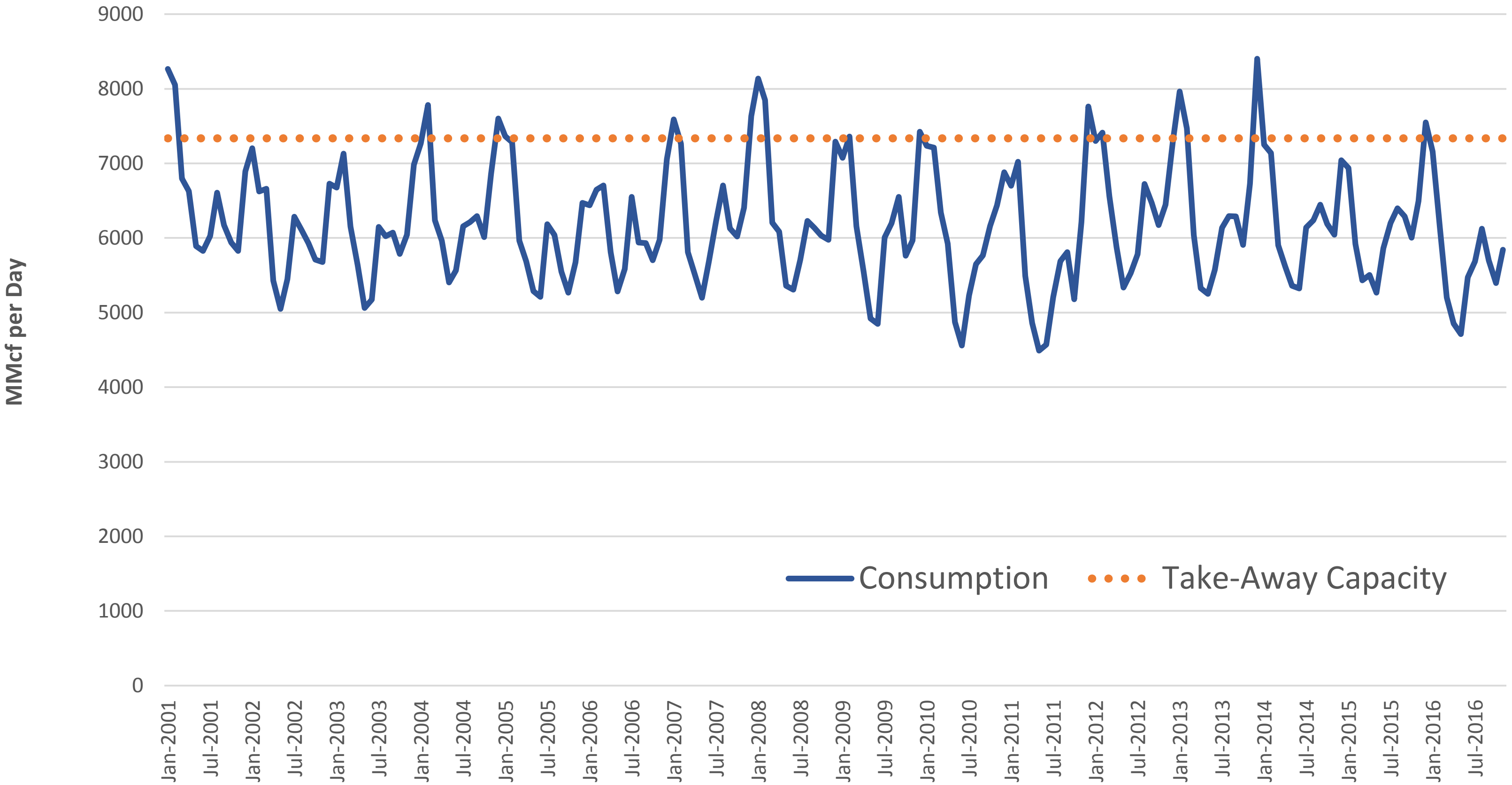


3. Winter Peak Day Demand

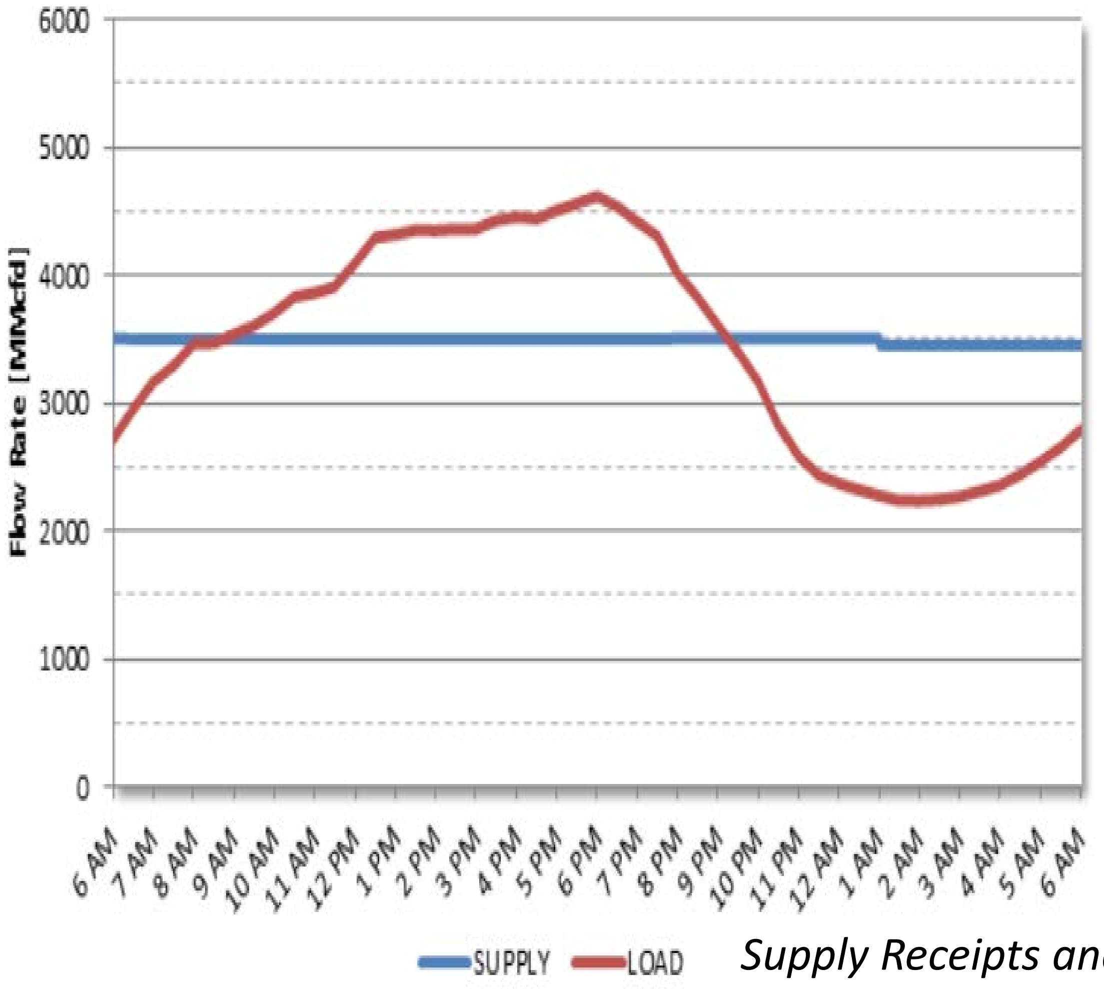
Winter peak demand is 11.8 Bcfd

Import capacity is 7.5 Bcfd

Shortfall is 4.3 Bcfd

Without storage, California would be unable to consistently meet winter demand for gas.

Gas storage functions



Supply Receipts and Total Load by Hour for SoCalGas September 9, 2015

4. Intraday Balancing

- Supports hourly changes in demand.
- Allows back up of renewable generation.

Source: Aliso Canyon 2016 Summer Technical Assessment

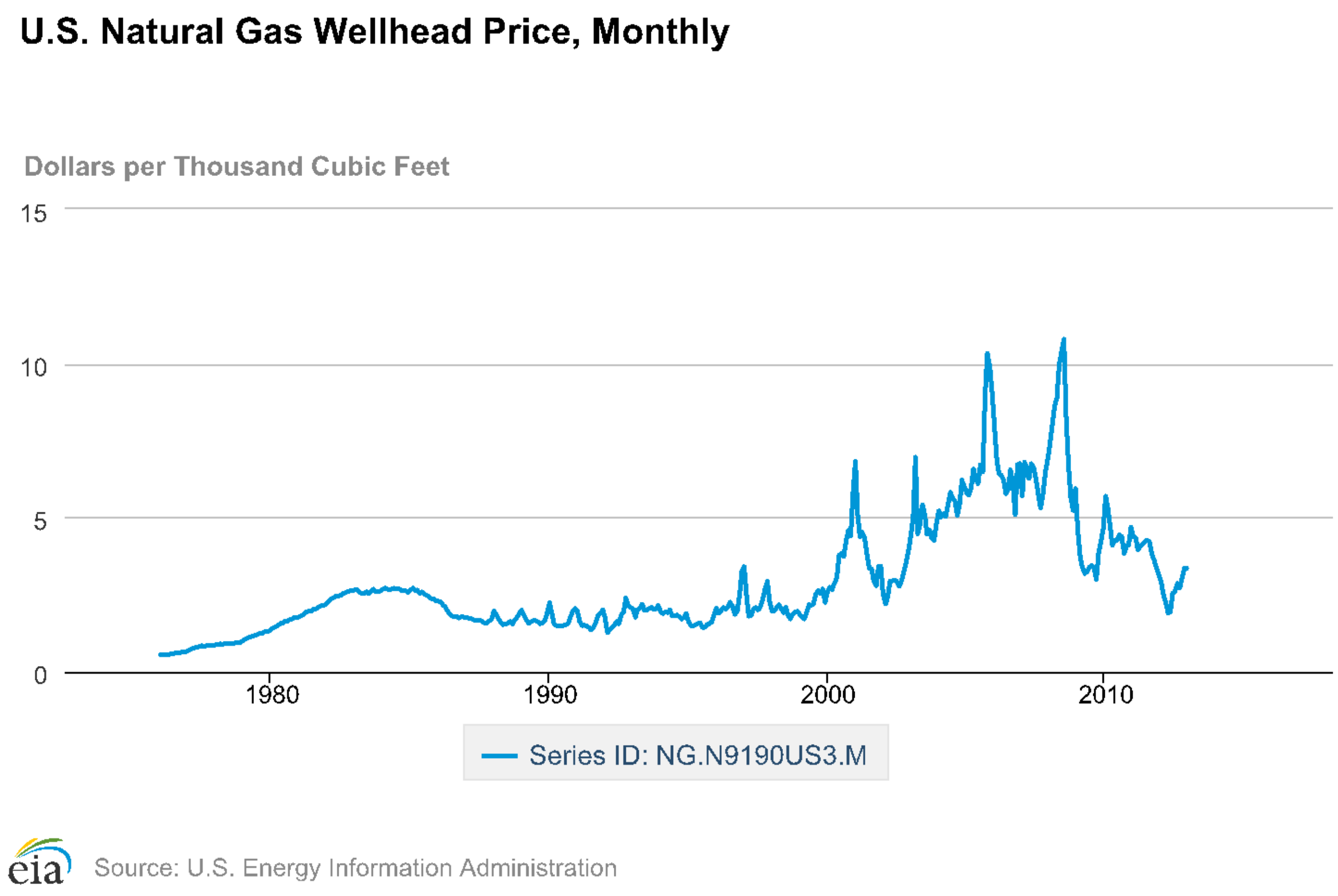
Gas storage functions

- 5. Gas storage provides gas and electric reliability during extreme weather and wild fires.
  - Problems may increase with climate change
  - These emergencies can threaten supply when demand simultaneously increases.

https://www.independent.com/news/2008/jul/03/early-morning-gap-fire-update/

Financial functions are secondary

- 6. Seasonal Price Arbitrage
  - Allows savings through seasonal price arbitrage
    - winter prices usually higher than summer prices
- 7. Liquidity/Short-term Arbitrage
  - Grants marketers a place to hold supply and take advantage of short-term prices for liquidity and short-term arbitrage.



The overarching reason for the utilities' underground gas storage is to meet the winter demand for gas.

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If storage can meet winter demand then it can do all the other functions:

- intraday balancing,
- compensating for steady production,
- creating an in-state stockpile for emergencies, and
- allowing arbitrage and market liquidity.

What could replace underground gas storage?

Additional pipelines could replace UGS

- Would cost approximately $15B
- Difficult to do by 2020 (maybe by 2025?)
- Shifts the risk of supply not meeting demand to upstream, out-of-state
- Is a further commitment to gas
- Presents its own set of risks

San Bruno fire
https://www.flickr.com/photos/pkingdesign/4975247309/

Replace UGS with LNG peak shaving units

To meet the 11.8 Bcfd extreme winter peak day demand forecast for 2020 would be extremely difficult to permit.

Would require about $10B.

http://www.russoonenergy.com/content/it-time-rethink-gas-storage-and-pipelines

Containerized LNG

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- 2,000 containers required to support a 50 MW power plant for four hours,
- Takes a day to recharge
- Container transportation would incur potential safety issues, increased emissions
- The number of containerized LNG units required to generate each MWh suggest containerized LNG does not appear viable at the scale required to replace California's 4.3 Bcfd winter peak
- May have application in meeting system peaks for a few hours or supporting power plant demands for a few hours.

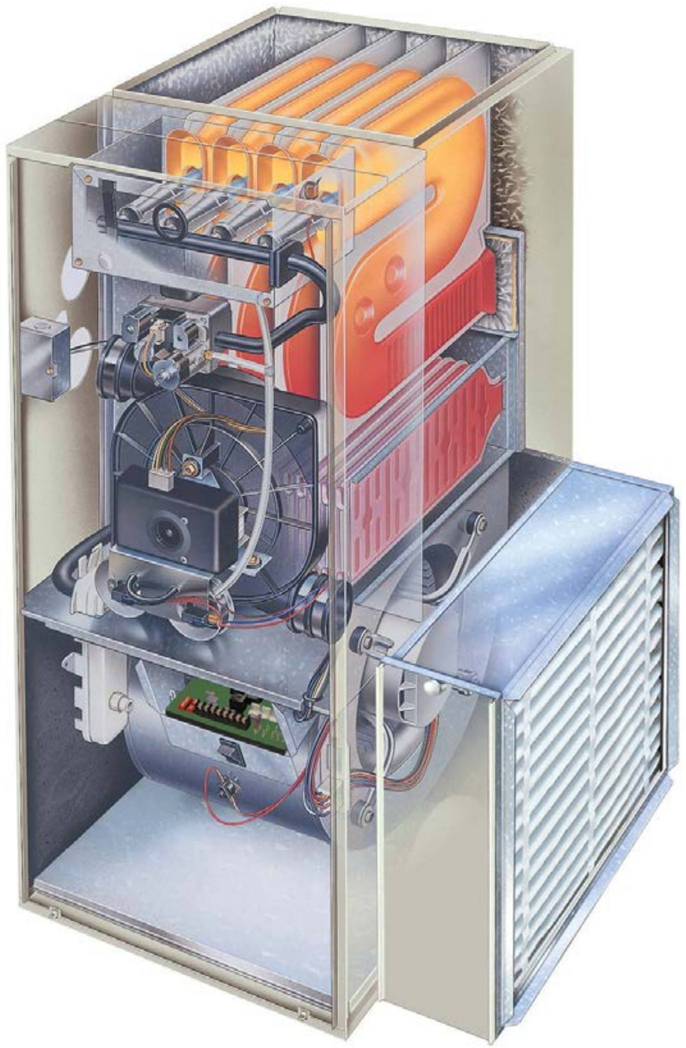
Figure 32. GE's CNG Technology Solution
Source: Photo courtesy of BHGE

L NG from Costa Azul

- LNG from Sempra's Costa Azul terminal in Mexico could provide 300 MMcfd to San Diego, and obviate this amount of gas storage in Los Angeles.

http://www.sandiegouniontribune.com/sdut-ensenada-municipal-government-orders-sempra-plant-2011feb11-htmlstory.html

Winter peak is for heat, not electricity



High efficiency gas furnace:
https://hvacdealers.com/blog/high-efficiency-gas-furnaces/

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No method of conserving or supplying electricity can replace the need for gas to meet the winter peak in the 2020 time frame including

- electricity storage,
- new transmission,
- energy efficiency measures, and
- demand response.

- The winter peak is caused by the demand for heat and heat will continue to be provided by gas, not electricity, in that time frame.
- Gas storage is likely to remain a requirement for reliably meeting winter peak demand.

Electricity could address the summer peak Caused by demand for air conditioning

- 15 GW of new transmission could offset about 30% percent of 2.8 average *summer* peak gas requirements.
- 50GW required for 100% plus the emission free supply to put on the grid
- Still doesn't meet the winter peak.

https://cleanenergygrid.org/gulf-coast-electricity-transmission-summit/

Operational and Market Mechanisms

- Regulatory and operational changes can help to reduce reliance on underground gas storage, but will not eliminate the need for these services.
  - Tighter Balancing Rules – small gains; already made
  - Core Customers Balancing to Load Instead of Forecast – small gains
  - Greater Use of Line Pack – already used
  - Closer Gas-Electric Coordination – already done
  - Shifting to Out-of-Area Generation on Gas-Challenged Days – still need winter heat
  - Day-Ahead Limits on Gas Burn – doing this now
  - Shaped Nominations and Flexible Services – could reduce peak
  - Weekend Natural Gas Market – requires agreement

There is no “silver bullet” to replace underground gas storage in the 2020 time frame

- We could not identify an alternative gas supply system that would:
  - meet the 11.8 Bcfd extreme winter peak day demand forecast and
  - allow California to eliminate all underground gas storage by 2020.

- Two possible longer-range physical solutions would
  - be extremely expensive
  - carry their own risks
  - incur barriers to siting
  - commit CA to more gas infrastructure

Take Away Messages: Key Question 2

- California needs natural gas and natural gas storage to meet the winter demand and winter peak daily demand for heat. Pipelines do not have the capacity to meet these demands.

- Replacing UGS would be very expensive and nearly impossible to do in the near term.

- Nothing done for electricity will have much effect on the peak winter demand because this demand is caused by demand for heat and CA has no policy to electrify heat.

Key Question 3

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How will implementation of California's climate policies change the need for underground gas storage in the future?

Dr. Jeffery B. Greenblatt
Chief Scientist, Emerging Futures LLC
(formerly Staff Scientist, Lawrence Berkeley National Laboratory)
Lead Author

Third Major Conclusion and Recommendation

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- **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 time scales, 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.

Key Question 3 Sub-Questions

- How might California's climate policies and new technology developments affect the need for gas storage in the future?
- How could regional grid operations and/or gas-electric coordination change the role of storage?
- How would storage need to change between today and 2050?

Energy scenarios

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- Examined 26 studies, more than 300 scenarios that looked at future energy systems (California, U.S., and a few global).
- No study provided sufficient detail to convincingly inform the future need for UGS in California.
- Recommendation 3.1: Commission studies to identify future configurations of the energy system with modeling of natural gas use on *all relevant time scales (subhourly to seasonal).*

Major uses of natural gas

Total gas demand

Non-electricity gas demand

Electricity gas demand

Ratio may change depending on future policy

Non-electricity gas demand	Electricity gas demand
Winter peak	Summer peak
Building heat drives most need for UGS today	May be exacerbated by renewable intermittency

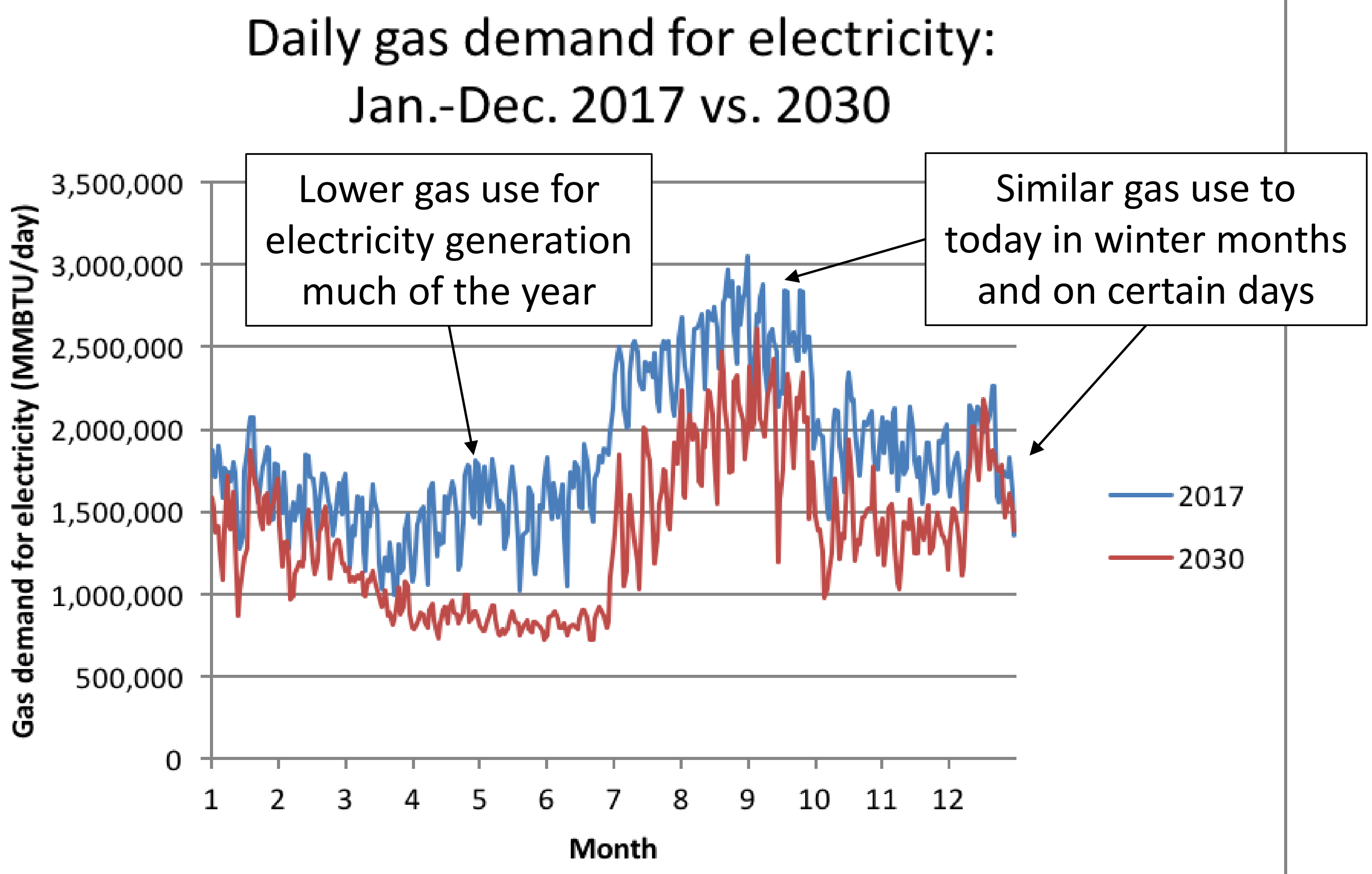
What will change by 2030?

Electricity gas:

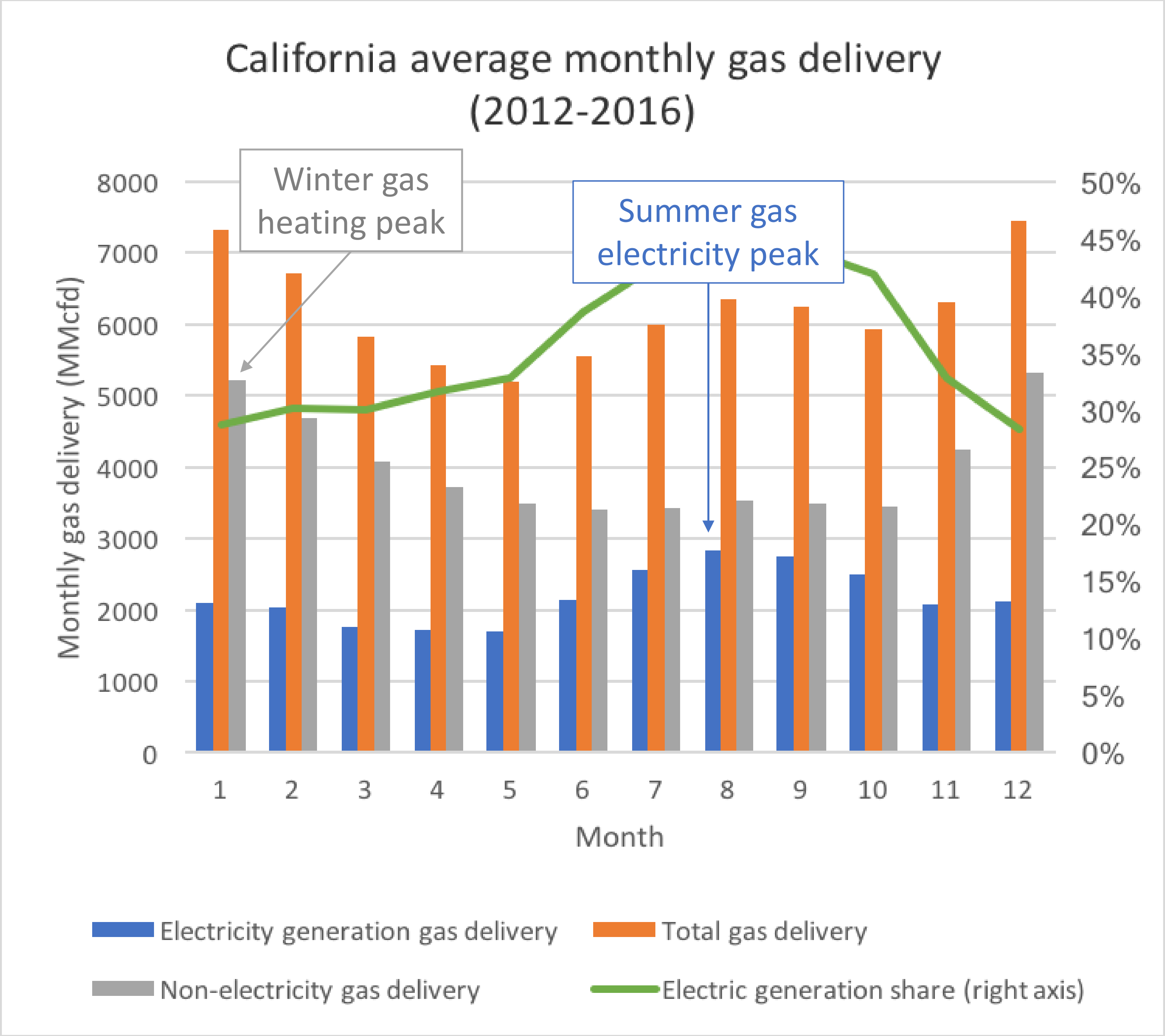
- Renewables will provide >50% of generation.
- Some energy efficiency, energy storage, demand response, and electric vehicle growth.

Non-electricity gas:

- Scenarios estimate that demand will decrease 11-22%, not enough to reduce the need for UGS.



CEC estimated 1-in-2 year daily average natural gas demand for electricity generation in California in 2017 vs. 2030.



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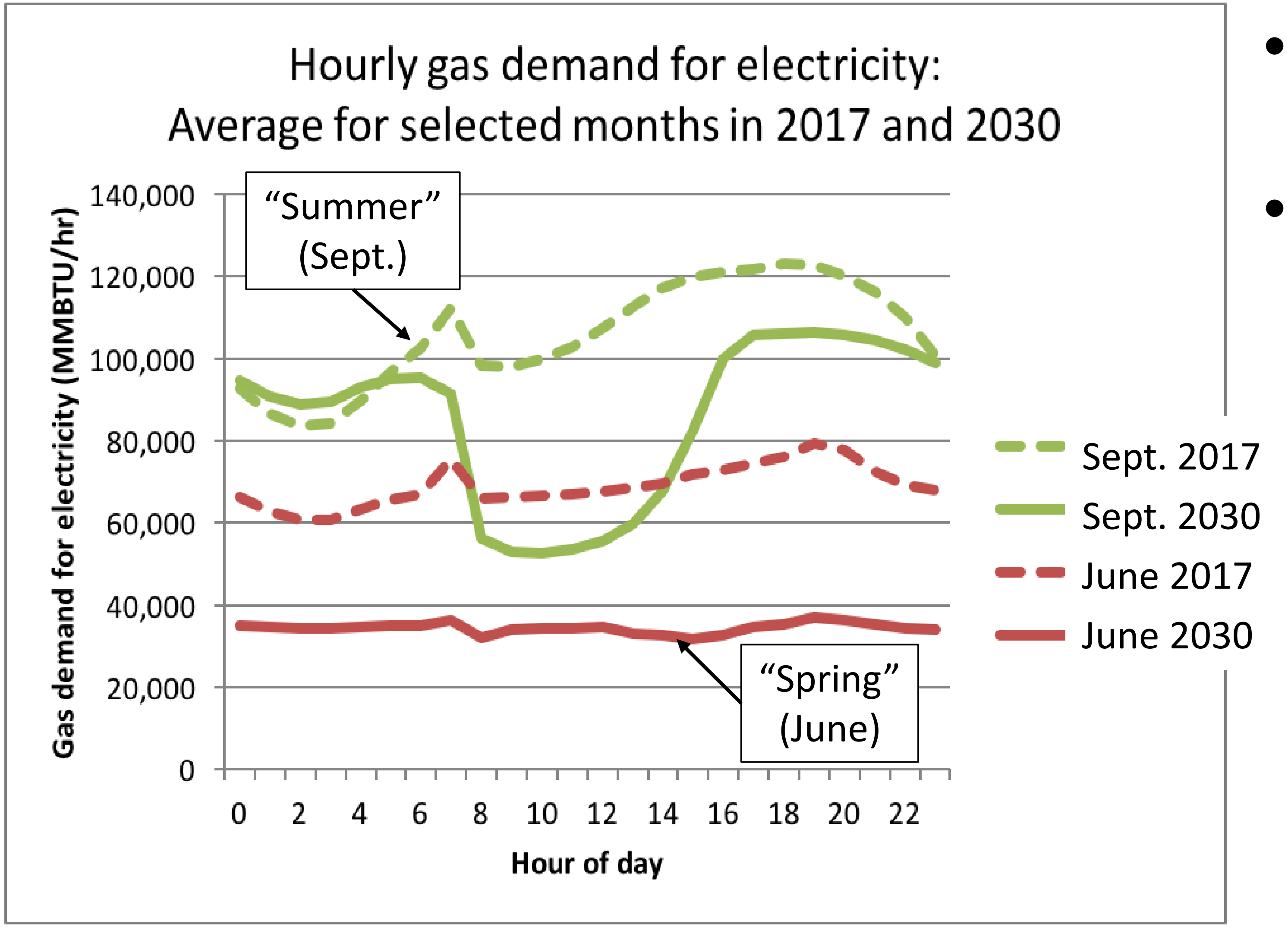
- Total gas demand peaks in winter, driven by gas heating demand
- Demand for gas-fired electricity peaks in summer
- All gas uses expected to reduce somewhat in 2030, but timing of peaks will remain similar to today
- By 2050, gas demand for both electricity and heat could change significantly relative to today

Changes in hourly gas electricity use



- Reduction in natural gas use, directly or indirectly
- However, changes do not necessarily reduce the need for underground gas storage (example: more intermittent renewable electricity)

CEC estimated Diurnal 1-in-2 year average monthly natural gas demand for electricity generation in California in 2017 vs. 2030. June and September averages shown.

Daily load balancing of electricity

- How to address *dunkelflaute* (“dark doldrums”) conditions?
- Peak electricity demand ~60,000 MW

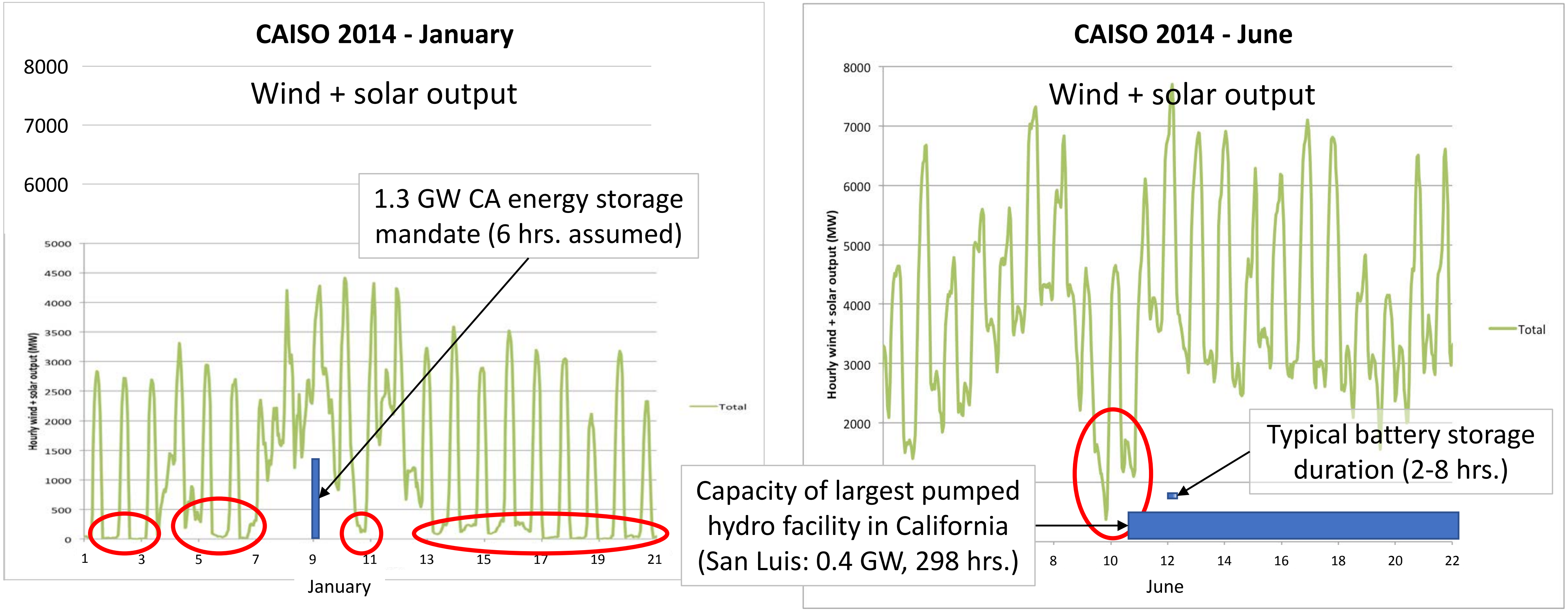
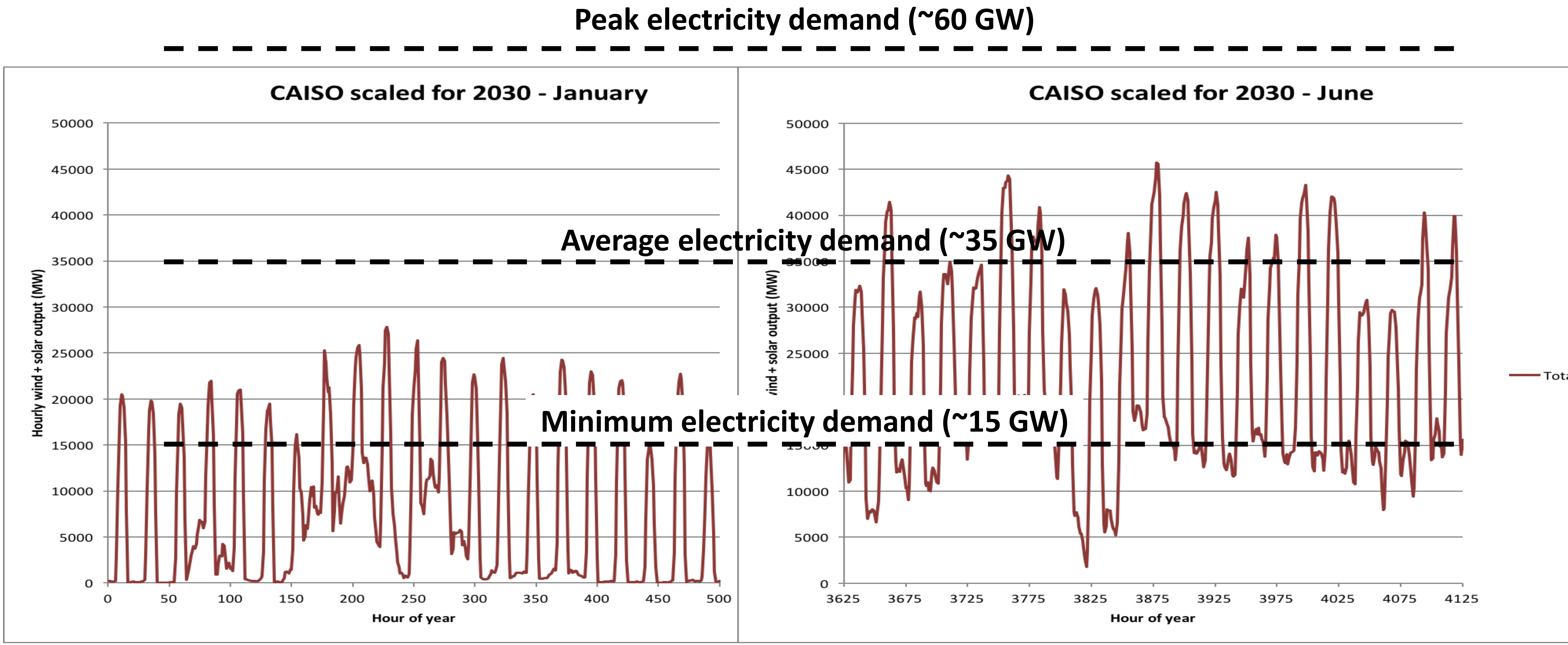


Figure ES-3.2. *Combined wind and solar output*

Projected 2030 electricity capacities



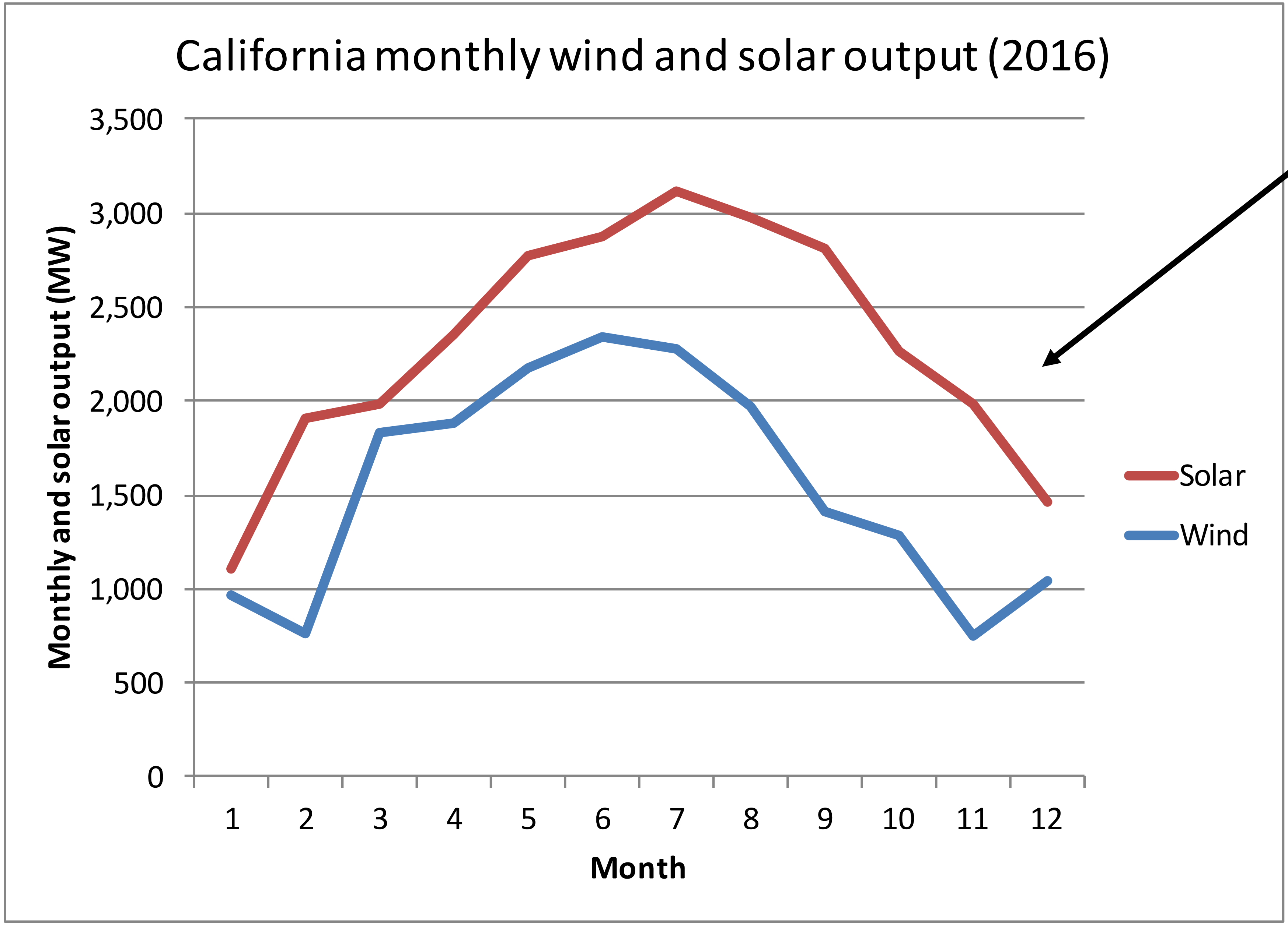


Figure 2. California monthly average wind and solar output in 2016. Reproduced from data in CAISO (2017a, Figure 1.8).

Demand for heat peaks in winter, when solar and wind outputs are minimal.

Electrified heat could be a key strategy in lowering emissions, but would further exacerbate supply-demand mismatch.

Required backup from gas equal to renewable energy capacity

Technology Assessment for 2030

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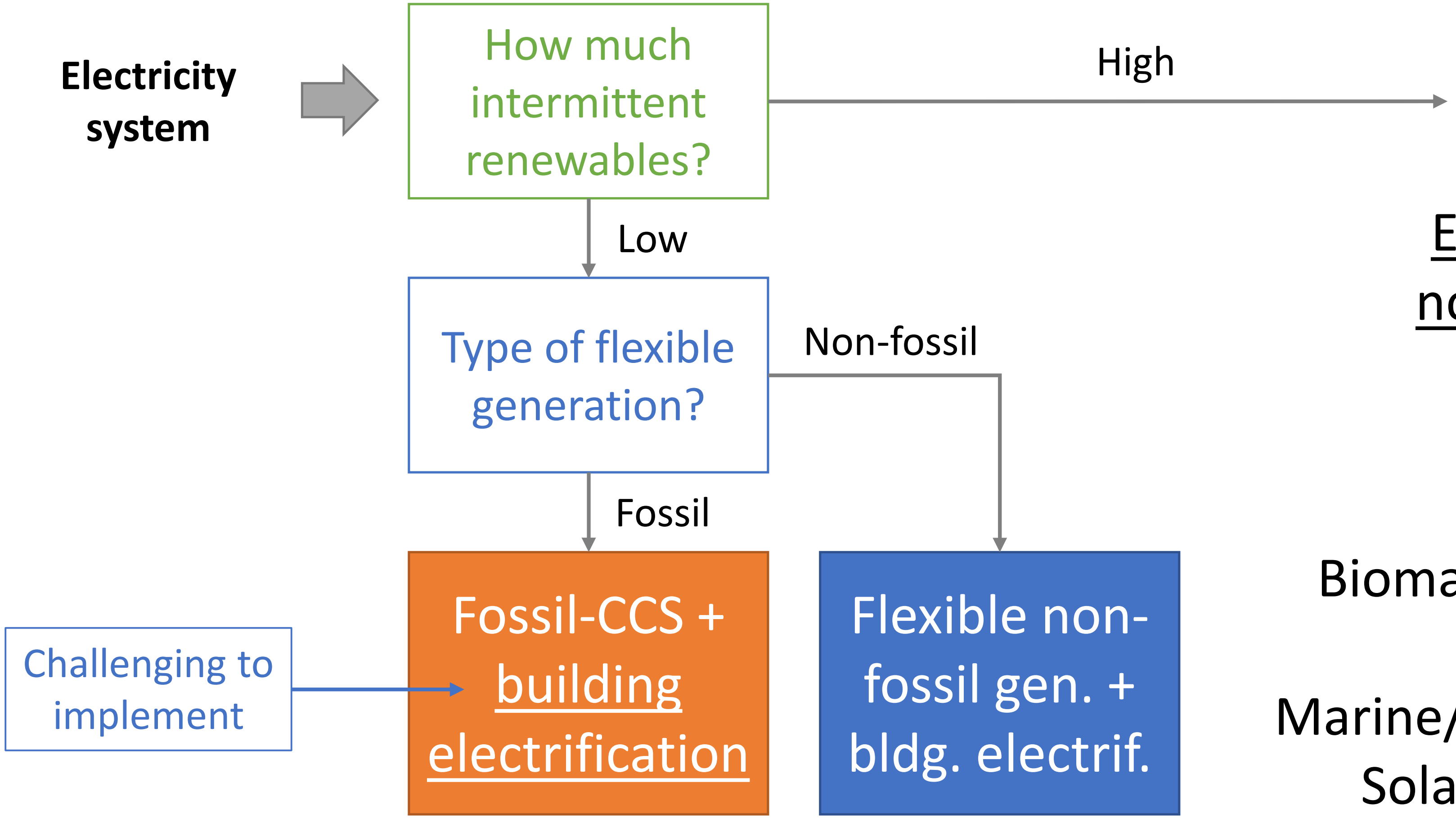
- Intraday balancing—managing changes in gas demand over a 24-hour period—could possibly be addressed by various forms of energy storage, flexible loads or imports/exports
- Multiday or seasonal supply-demand imbalances must be addressed with low-GHG chemical fuels:
  - Examples: biomethane, synthetic natural gas, and hydrogen (H_2)
  - Have same storage challenges as natural gas
  - CO_2 from fuel production may also need to be managed
  - May introduce new constraints (e.g., H_2 or CO_2)
- The total amount of UGS needed unlikely to change by 2030

Logic diagram for 2050 scenarios

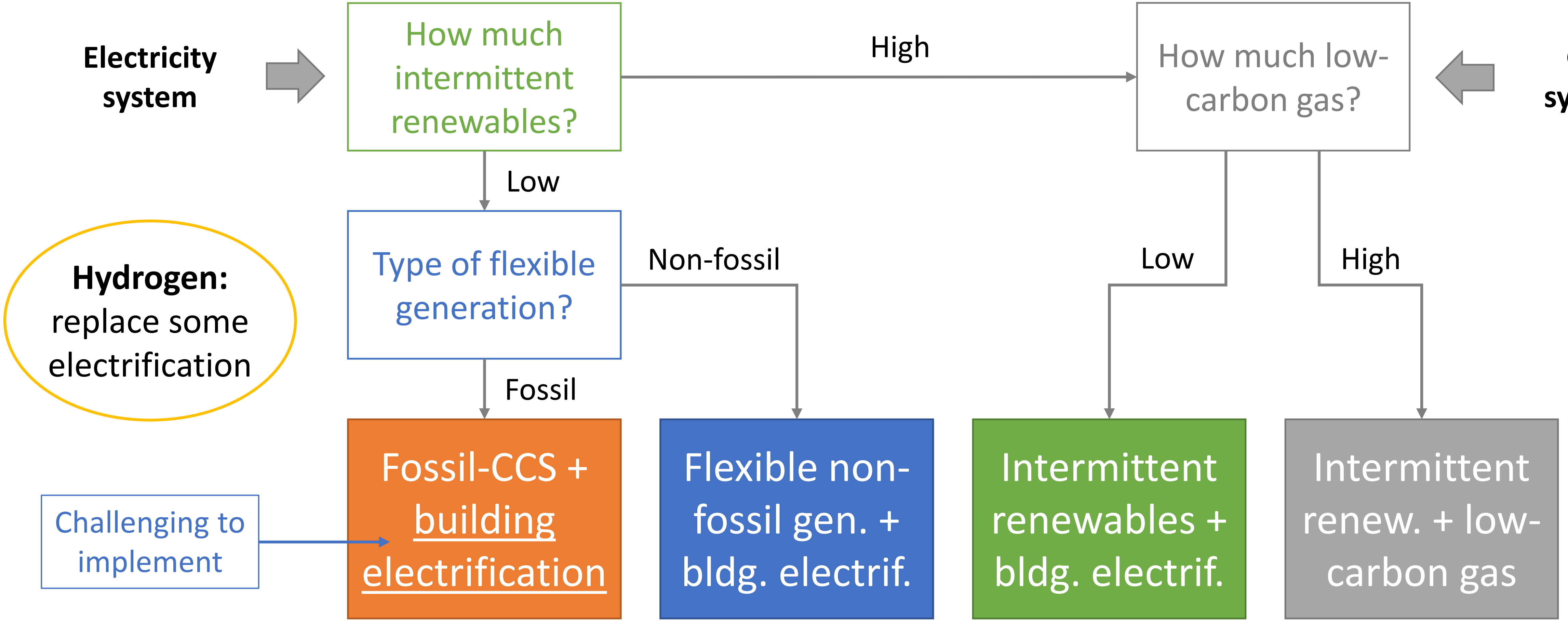


NG use vs. today:	~150%	~40%
Net UGS impact:	Increase	Decrease
New storage needed:	Yes (CO_2)	No

Examples of flexible, non-fossil generation:

Nuclear
Geothermal
Biomass (with or without CCS)
Hydropower
Marine/hydrokinetic technologies
Solar thermal with storage
Offshore/high-altitude wind
Etc.

Logic diagram for 2050 scenarios



NG use vs. today:	~150%	~40%	~60%	~100%
Net UGS impact:	Increase	Decrease	Unclear	Unclear
New storage needed:	Yes (CO_2)	No	No	Maybe (H_2, CO_2)

Conclusions and Recommendations

Flexible, non-fossil generation might minimize reliability issues currently stabilized with natural gas generation.

There are widely varying ideas about energy systems that might meet the 2050 climate goals. Some of these would involve some form of gas (methane, hydrogen, CO_2) infrastructure including underground storage, and some may not require as much UGS as in use today.

California should evaluate the relative feasibility of achieving climate goals with various reliable energy portfolios, and determine from this analysis the likely requirements for any type of UGS in California.

Take Away Messages: Key Question 3

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- Energy storage, flexible loads, and imported (or exported) electricity could play a role in firming intermittent renewable energy.
- Only chemical energy storage—which requires UGS—can supply power in *dunkelflaute* conditions for multiple days and seasonally.
- Electrification of heat could increase electricity demand in winter at the same time that solar and wind output declines.
- More flexible, non-intermittent or baseload low-GHG resources (e.g. geothermal, CCS, nuclear, WY wind, wave power, etc.) could reduce UGS use significantly.
- California needs a plan for energy that accounts for both capacity and reliability at all time scales.

Concluding Remarks

- With appropriate regulation and oversight, the risks associated with underground gas storage can be managed and and mitigated.
- California's energy system currently *needs* natural gas and gas storage to run reliably.
- California's current energy planning does not include adequate feasibility assessments of the possible *reliable and low carbon* future energy system configurations.

Questions?