Abstract

The Aliso Canyon natural gas storage field came into public view on October 23, 2015 because of a leak detected in one of its 114 storage/injection wells. The leak was the second largest gas storage leak in U.S. history, reported by Conley and co-authors in Science, March 18, 2016 to release 97,100 metric tons of methane. Ten percent of the release has been reported as ethane. This was the largest such event in the U.S., in terms of greenhouse gas impacts, because explosion and fire converted the earlier methane to CO₂. The field is the largest of the four fields serving southern California, with 86.2 billion cubic feet of working gas capacity. In addition to its size, the fifth largest in working gas nationwide, its ability to deliver massive quantities in a short time is a valuable operational feature. It can send out a maximum of 1.86 billion cubic feet per day, making it the fastest in California, the tenth fastest in the nation and, among depleted reservoirs, the fourth fastest in the nation (only salt domes are faster). Its capabilities are particularly useful for serving the electric power industry whose demands fluctuate sharply and which comprise 60% of SoCalGas company’s load (demand) in the summer [SoCalGas is a unit of Sempra Energy]. A relief well extinguished the leak on February 11 [cemented Feb. 18], 2016. As of mid-June 2016, the field was still being withheld from operation while a series of integrity tests were being conducted on its 114 injection wells. Imposed by the state’s Division of Oil, Gas and Geothermal Resources and further reinforced by legislation in May, these involve temperature and noise tests, followed by logging to inspect casing (thinning) and cement bonds with production casing and with the formation, running a multi-arm caliper tool to reveal deformation or thinning, and finally pressure testing. In May, SoCalGas estimated total costs to reach $650 million, 15% each for well control and legal fees, and 70% for relocation expenses [$717 M by June 30]. Many entities have coordinated analysis of risk and development of procedures to avoid blackouts due to insufficient gas supplies, the first concern being able to serve high electricity demands during summer heat waves. This requires understanding planned and unplanned deliverability risks (pipelines) and electric system risks, separately and together. The event illustrates the close interdependence and urgent coordination required between gas transmission and storage, the electric sector, and a host of regulatory bodies.

*Note: The amount the electric generation share of SoCalGas load exceeds 60% during peak hours is unknown to the author. The facility remains offline with 23 wells fully passed as of Sept. 16, 2016 DOGGR report and three more per Oct. 6 online summary.
Aliso Canyon
Gas Storage Leak Disaster and Response

AAPG 2016 PS/RMS Las Vegas – October 5, 2016

Jeremy Platt
“energy research management and analysis”
Palo Alto

Google Earth Imagery Date 2/8/2016

650-815-8601
jbplatt@earthlink.net

LAX 25 mi.
The Invisible Catastrophe

Over the course of four months, 97,100 metric tons of methane quietly leaked out of a single well into California’s sky. Scientists and residents are still trying to figure out just how much damage was done.

BY NATHANIEL RICH  MARCH 31, 2016
Some Geologic Curiosities

• **First “commercially successful” oilfield** in Calif./Western US is ~5 miles NW of Aliso Canyon: Pico Canyon Oilfield. Operated from 1876-1990.

• **Greatest uplift** from 1994 Northridge Earthquake occurred practically on top of Aliso Canyon oilfield. (most expensive U.S. earthquake)
The Magnitude 6.7 Northridge, California, Earthquake of 17 January 1994
Figure 4, Science, 21 October 1994


by Scientists of the U.S. Geological Survey and the Southern California Earthquake Center
Disaster

• **Well failure** at SoCalGas’ Aliso Canyon facility. Discov. Oct 23. 7 kill attempts. Relief well success Feb 11.
  > Largest facility in W. US.
  > Provides 66% of useful storage to S. Calif. (!!!)
  > Facility is particularly important to deliverability due to S Calif. and LA Basin pipelines/load configuration.

• **Magnitude**: 84,200 MT methane; 4.62 Bcf*. “Weight of aircraft carrier.” 12% of CA dairy emissions in CO$_2$e.

• **Major impacts** from proximity to urban communities.

• **$717 million costs** through June 30.
  > 70% relocation, cleaning
  > 15% well control, root cause analysis
  > 15% legal, lost gas, mitigation

> **181 lawsuits** as of July 28.

*SoCalGas est. May 26, 2016.
MT = metric ton; Bcf = billion cubic feet
Emissions Trend


Rate

Hydrocarbon leak rate, metric tons per hour

Well failure 23 Oct 2015

50 = ~2.5 mmcf/hr

20 = ~1.0 mmcf/hr

Cumulative

CH₄ released, metric tons x 10³

Control restored 11 Feb 2016

Total CH₄ released

97,100 metric tons
(5.0 billion SCF)

86,000

84,200
Relocation Program $$$

• May 16 tally
  “...more than \textbf{30,000 resident visits} at our Community Resource Center, provided temporary \textbf{housing for 8,000 families}, processed more than \textbf{41,000 reimbursements} totaling $76\text{ million}, installed \textbf{38,000 air filtration systems}, and cleaned public parks, playgrounds, and schools.” -- \textit{SoCalGas news release}

• Program was initially proposed to end Feb. 26. Later, it transitioned individuals from hotels to temporary residences; incorporated indoor air sampling and other measurements; involved various court proceedings (vs. County of LA in Superior Court and Court of Appeal).

• Eventually extended to as late as June 7\textsuperscript{th}. 
Response

• Many agencies involved (Governor’s office, state, local, federal interagency initiative), others.
• Cause still under investigation.
• Facility is out of service until all wells tested or withdrawn. Restriction to only use production tubing will reduce future per-well flows to 40%-80%.
• Electric generation reliance (~60% of summer demand on SoCalGas’ system) led to special procedures for gas-electric coordination.
• Summer – dodged a bullet. Winter also poses risks.
Many Agencies (1)

**Governor of California**
- Office of Emergency Services (Cal OES)
- Attorney General

**Well Control and Testing**
California Public Utilities Commission (CPUC)
- Safety and Enforcement Division (SED)
California Department of Conservation
- Division of Oil, Gas and Geothermal Resources (DOGGR)
  - Panel: Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory and the Sandia National Laboratory
  - Consultant: Blade Energy Partners

**Air Monitoring and Public Health**
South Coast Air Quality Management District (SCAQMD)
California Air Resources Board (CARB)
California Environmental Protection Agency
  - Office of Environmental Health Hazard Assessment (OEHHA)
    - Panel: UC Irvine, UC Davis, UCSF, UC Riverside, UC Berkeley/LBNL, UCLA
California Energy Commission (CEC)
  - Consultant: Scientific Aviation (emissions)
Los Angeles Emergency Management Department (EMD)
County of Los Angeles
  - Dept of Public Health, Fire Dept, Office of Emergency Mgmt, District Attorney
Many Agencies, Others (2)

Worker Safety
California Dept of Industrial Relations
  >Division of Occupational Safety and Health (Cal/OSHA)

Energy Impacts / Gas-Electric Coordination
California Public Utilities Commission (CPUC)
California Energy Commission (CEC)
  > Consultants: Walker & Associates (gas flow modeling), Los Alamos Nat’l Laboratory
California Independent System Operator (CAISO)
Federal Energy Regulatory Commission
Department of Energy (DOE)

Interagency Task Force on Natural Gas Storage Safety
  > Department of Energy (DOE)
  > Department of Transportation (DOT)
    -Pipeline and Hazardous Materials Safety Administration (PHMSA)

Companies
NG: SoCalGas (SCG) [SEMPRA Energy], San Diego Gas and Electric (SDG&E)
Electric: Los Angeles Dept Water and Power (LADWP), Southern California Edison (SCE) and San Diego Gas and Electric (SDG&E)

Other Groups and Organizations
Call for Federal Task Force on Aliso Canyon
(ln later incorp. as Nat Gas Storage Safety Amendment
in 2016 “bipartisan energy bill”

Live Webcast
Joint Agency Workshop on Aliso Canyon Action Plan for Local Energy Reliability

Webcast Screenshot, August 26 2016 webcast)
Well Control Timeline

“Update on Aliso Canyon Methane” (arb.ca.gov)
California Environmental Protection Agency Air Resources Board (CARB), Feb 16.

Oct 23: 77 Bcf working gas.

Dec 4: Began drilling relief well

12/27: 49.5
Jan 23 SCAQMD: Stop all injections

1/10: 32

Feb 10: 15 Bcf.
Cumulative withdrawals: 57 Bcf plus ~5 Bcf losses.
CPUC: No further withdrawals. Hold at 15 Bcf.

Sources: SoCalGas News Release, SER Form 8-Q, SoCalGas AC Updates; CARB.
Root Cause Still Under Investigation

...by Blade Energy Partners for DOGGR and CA PUC SED (Safety and Enforcement Division)

If dimensions correct, cross-section area of prod. casing is ~6X greater than that of tubing.
Soil eroded by gas and fluid during well-kill pumping operations.
Well Testing Procedures

1. **Temperature and Noise logs.** Expanding gas through a casing leak will expand, cool. Streaming gas in well bore should make noise.
   
   __________ repair, retest, proceed or take out of op’n __________

2. **Casing Wall Thickness inspection.** Pull tubing. If thinning, calculate strength to withstand operating pressures plus a margin for safety.

3. **Cement Bond log.** Pull tubing. Assess bond between cement and casing, between cement and formation. Along well and anchor.

4. **Multi-Arm Caliper inspection.** Assess well shape, deformations. Must withstand 115% of max operating pressure.

5. **Pressure Tests.** Test performance of (a) tubing and (b) annular space between tubing and casing, plus integrity of packers.
   
   __________ repair, retest, obtain approval, or take out of op’n __________

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Rate of progress to move well from “pending” to “passed”?

- S. Cal. Generation Coalition: about one per week.
- Observed, Sept. 2-16: 1 ½ per week.
Impacts

• “End of pipe” configuration
  – Vital role of storage

• Unprecedented gas-electric coordination
  – Energy to >20 million at risk
  – Electric generation, 60% of summer demand
  – Multiple agencies; special rules required “on the fly”
  – Summer, Winter Action Plans (latest used “hydraulic” anal.)

• How did we get through the summer?

Example High Stress Day
(High Electric Load)
Used in Aliso Canyon Studies
Sept 9 2015

Source: LCG Consulting/EnergyOnline
Processing of CA ISO data
Regional Characteristics: End of Pipe

- 90% of S. Cal gas from out of state

Pipeline Supplies mmcf/d to S Cal.
1. 150
2. 160
3. 765
4. 1,590
5. 1,210

3,875 (maximum flows)

California Gas Report, 2016
Regional Characteristics: SoCalGas System

<table>
<thead>
<tr>
<th>Storage Stats</th>
<th>Aliso C.</th>
<th>La Gol.</th>
<th>H Ran.</th>
<th>PdR</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working Gas Bcf</td>
<td>86.2</td>
<td>21.5</td>
<td>26</td>
<td>2.4</td>
<td>136.1</td>
</tr>
<tr>
<td>Max Withdrawal (MMcfd)</td>
<td>1,860</td>
<td>420</td>
<td>1,000</td>
<td>400</td>
<td>3,760</td>
</tr>
</tbody>
</table>

Normal Times: Heavy Use of Aliso C.

Sempra’s ENVOY system tracks daily operations, OFO’s (Flow Orders), maintenance, etc.

(1) Storage Inventory

(2) Average Days of Withdrawals from Aliso Canyon, 2012-2015

<table>
<thead>
<tr>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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</thead>
<tbody>
<tr>
<td>31</td>
<td>28</td>
<td>18</td>
<td>7</td>
<td>3</td>
<td>5</td>
<td>13</td>
<td>18</td>
<td>12</td>
<td>12</td>
<td>26</td>
<td>31</td>
</tr>
</tbody>
</table>
Demand and Supply

Average Seasonal Demand: Flip-flop in Share of Electric Generation

*Should electric gen. remain as primary party to balance supply/demand?*

<table>
<thead>
<tr>
<th>Segment</th>
<th>Summer Peak</th>
<th>% of Peak</th>
<th>Segment</th>
<th>Winter Peak</th>
<th>% of Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>0.6 Bcf</td>
<td>20</td>
<td>Core</td>
<td>3.0 Bcf</td>
<td>60</td>
</tr>
<tr>
<td>Electric</td>
<td>1.9 Bcf</td>
<td>60</td>
<td>Electric</td>
<td>1.0 Bcf (*?)</td>
<td>20</td>
</tr>
<tr>
<td>Noncore, not electric (*0.5 Bcf = refineries)</td>
<td>0.6 Bcf*</td>
<td>20</td>
<td>Noncore, not electric (*0.5 Bcf = refineries)</td>
<td>1.0 Bcf*</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>3.2 Bcf</td>
<td>100</td>
<td>Total</td>
<td>5.1 Bcf</td>
<td>100</td>
</tr>
</tbody>
</table>

*PUC Feb 16, 2016 estimates*  
(?) SoCalGas recently estimating 0.2 less

Winter is Critical Period as Demand and Supply Risks Escalate

<table>
<thead>
<tr>
<th>Supply/Demand</th>
<th>Design (Bcf/day)</th>
<th>Recent Experience (Bcf/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipeline Capacity Supply</td>
<td>3.8</td>
<td>3.0</td>
</tr>
<tr>
<td>Other Storage Supply (excluding Aliso)</td>
<td>1.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Peak Winter Gas Demand</td>
<td>(5.0)</td>
<td>(5.0)</td>
</tr>
<tr>
<td>Reserve Margin</td>
<td>0.5</td>
<td>(1.0)</td>
</tr>
</tbody>
</table>

Source: CPUC Energy Division *Preliminary Staff Analysis*

Note 1: Typical outages can reduce capacity 0.5-1.0 Bcf/day
Note 2: Electric generation typically requires 1.0-2.0 Bcf/day
Getting Through the Summer


Source: Custom charts from LCG Consulting/Energy Online, drawing on CAISO data
Getting Through the Summer

2. Major benefit from tighter balancing (fr. +/- 10% to +/- 5%)

<table>
<thead>
<tr>
<th></th>
<th>Max Under scheduled 2015</th>
<th>Max Under scheduled 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>June</td>
<td>188</td>
<td>93</td>
</tr>
<tr>
<td>July</td>
<td>226</td>
<td>69</td>
</tr>
<tr>
<td>August</td>
<td>225</td>
<td>18</td>
</tr>
</tbody>
</table>

>0 Under scheduled (too little gas)

<0 Over scheduled

3. Reduced demand on hottest days.

CPUC est.

CAISO est.
Looking Ahead

Special Procedures Continue (about ten)

• Get Aliso C. back in service. Need **36 wells** for a minimum **420 mmcf/d**.
  – Better: 1,119 mmcf/d, ~96 wells.
  – 9/16: **23 passed**, 15 pending, 78 taken out of operation*
    – IR scanning, daily inspect, ...
• Continue tight scheduling, conservation, etc.
• Favor gen. outside the LA Basin (by raising in-Basin NG costs before committing, up 25% to as much as 200% plus $2.50)
• Acquire LNG from Baja? (could obtain 200 mmcf/d)

Concerns Raised in Winter Action Plan Review

• Don’t just plan for extreme days, plan for multiple difficult days.
  – Recall well freeze-offs, not so long ago.
• Hydraulic modeling is superior to capture intraday flows
• Place tighter balancing requirements on “core” not just “non-core”?
  – Controversial
  – SoCalGas says this is already happening or is not feasible.
• Broaden scope across the West

*Well status reports issued by DOGGR 1st and 3rd Fridays.
Addendum
### Descriptive Statistics of Storage Fields

<table>
<thead>
<tr>
<th>Descriptive Statistic</th>
<th>Aliso Canyon</th>
<th>La Goleta</th>
<th>Honor Rancho</th>
<th>Playa del Rey</th>
<th>Total All Fields</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year Field Placed in Service</td>
<td>1973</td>
<td>1941</td>
<td>1975</td>
<td>1942</td>
<td>-</td>
</tr>
<tr>
<td>Injection/Withdrawal/Observation Wells (number)</td>
<td>115</td>
<td>20</td>
<td>40</td>
<td>54</td>
<td>229</td>
</tr>
<tr>
<td>Gas Compressor Units (number)</td>
<td>8</td>
<td>8</td>
<td>5</td>
<td>3</td>
<td>24</td>
</tr>
<tr>
<td>Compression Horsepower (bhp)</td>
<td>42,000</td>
<td>5,700</td>
<td>27,500</td>
<td>6,000</td>
<td>81,000</td>
</tr>
<tr>
<td>Maximum Reservoir Pressure (psig)</td>
<td>3,600</td>
<td>2,050</td>
<td>4,400</td>
<td>1,700</td>
<td>-</td>
</tr>
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<td>400</td>
<td>3,760</td>
</tr>
<tr>
<td>Maximum Injection Rate (MMcfd)</td>
<td>600</td>
<td>140</td>
<td>300</td>
<td>75</td>
<td>1,115</td>
</tr>
<tr>
<td>Maximum Well Depth (feet)</td>
<td>10,691</td>
<td>6,912</td>
<td>13,300</td>
<td>6,575</td>
<td>-</td>
</tr>
<tr>
<td>Minimum Well Depth (feet)</td>
<td>6,997</td>
<td>4,247</td>
<td>9,165</td>
<td>6,049</td>
<td>-</td>
</tr>
<tr>
<td>Average Well Depth (feet)</td>
<td>8,146</td>
<td>4,886</td>
<td>9,959</td>
<td>6,339</td>
<td>-</td>
</tr>
</tbody>
</table>

2016 General Rate Case before Calif. PUC, SOCALGAS Direct Testimony of Phillip E. Baker, UNDERGROUND STORAGE November, 2014


Withdrawal rate declines with drawdown. Normal times max modeled by SCG is **1.5 Bcf/d**

Starts to decline at 37 Bcf inventory. Drops to 0.54 Bcf/d near exhaustion. --**Prelim CPUC staff report, Feb 16, 2016**
To Get Informed

1. Sempra’s 10Qs!
   [Mark One] 
   [X] QUARTERLY REPORT PURSUANT TO SECTION 13 OR 15(d) OF THE SECURITIES EXCHANGE ACT OF 1934
   For the quarterly period ended June 30, 2016
   or
   [ ] TRANSITION REPORT PURSUANT TO SECTION 13 OR 15(d) OF THE SECURITIES EXCHANGE ACT OF 1934
   For the transition period from __________ to __________

2. CPUC (Pub. Util. Comm.)
   http://www.cpuc.ca.gov/aliso/

3. SoCalGas news
   https://www.socalgas.com/newsroom

4. Well tests etc. (DOGGR)
   http://www.conservation.ca.gov/dog/Pages/AlisoCanyon.aspx

5. CAISO: “Aliso Canyon gas-electric coordination”

6. Calif. Energy Commission

NOTE 11. COMMITMENTS AND CONTINGENCIES

LEGAL PROCEEDINGS

We accrue losses for a legal proceeding when it is probable that a loss has been incurred and the amount of the loss can be reasonably estimated. However, the uncertainties inherent in legal proceedings make it difficult to estimate with reasonable certainty the costs and effects of resolving these matters. Accordingly, actual costs incurred may differ materially from amounts accrued, may exceed applicable insurance coverage and could materially adversely affect the Company's results of operations, financial condition, liquidity or capital resources.

SoCalGas

Aliso Canyon Natural Gas Storage Facility Gas Leak

On October 23, 2015, SoCalGas discovered a leak at one of its injection and withdrawal wells, SS25, at its Aliso Canyon natural gas storage facility, located in the northern part of the San Fernando Valley in Los Angeles County. The Aliso Canyon facility has been operated by SoCalGas since 1972. SS25 is more than one mile away from and 1,200 feet above the closest homes. It is one of more than 100 injection and withdrawal wells at the storage facility.

Stopping the Leak, and Local Community Mitigation Efforts. SoCalGas worked closely with several of the world's leading experts to stop the leak, including planning and obtaining all necessary approvals for drilling relief wells... etc.
EIA Issues New Info due to Aliso Canyon

Also EIA just commented on S. California natural gas price volatility

--EIA Natural Gas Weekly
Sept 23, 2016
## Power Plants Served by Aliso Withdrawal

<table>
<thead>
<tr>
<th>Electric Generation Station</th>
<th>Capacity (Megawatts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. LADWP Haynes Generation Station</td>
<td>1,724</td>
</tr>
<tr>
<td>2. LADWP Scattergood Generation Station</td>
<td>803</td>
</tr>
<tr>
<td>3. LADWP Valley Generation Station</td>
<td>573</td>
</tr>
<tr>
<td>4. LADWP Harbor Generation Station</td>
<td>466</td>
</tr>
<tr>
<td>5. SCE Alamitos Toll</td>
<td>1,970</td>
</tr>
<tr>
<td>6. SCE Huntington Beach Generating Station</td>
<td>452</td>
</tr>
<tr>
<td>7. SCE Redondo Beach</td>
<td>1,343</td>
</tr>
<tr>
<td>8. SCE Barre Peaker</td>
<td>45</td>
</tr>
<tr>
<td>9. SCE Center Peaker</td>
<td>45</td>
</tr>
<tr>
<td>10. El Segundo Energy Center, LLC</td>
<td>526</td>
</tr>
<tr>
<td>11. Long Beach Generation, LLC</td>
<td>260</td>
</tr>
<tr>
<td>12. City of Glendale</td>
<td>288</td>
</tr>
<tr>
<td>13. City of Burbank</td>
<td>139</td>
</tr>
<tr>
<td>14. City of Pasadena</td>
<td>203</td>
</tr>
<tr>
<td>15. City of Anaheim - Canyon Power</td>
<td>200</td>
</tr>
<tr>
<td>16. City of Vernon - Malburg</td>
<td>138</td>
</tr>
<tr>
<td>17. S. Calif. Public Power Authority – Magnolia</td>
<td>328</td>
</tr>
</tbody>
</table>

**Total:** 9,503

Joint Agencies’ Aliso Study Stress Days

Source: Custom charts from LCG Consulting/Energy Online, drawing on CAISO data
Calif. Electricity Gen. Trends

Gas Use After Loss of SONGS, Gain of Solar & Wind

2012 shocks: Loss of nuclear, start of drought. Solar surge still small part of total.

NG: At 1:1 replacement, need ~3,000 MW NG gen with ~355 mmcf/d to replace SONGS. NG also vital to address “once through cooling” compliance.

CAISO gen trends, as portrayed by LCG Consulting/EnergyOnline*

* M Hassanzadeh, personal communication, Sept. 29, 2016
CAISO Overview: “The reliability of the LA Basin and San Diego have been impacted by the SONGS closure, the scheduled retirement of once-through cooled resources, and most recently, gas supply concerns: ”