

# Lawrence Berkeley National Laboratory

## LBL Publications

### Title

Revisiting underground gas storage as a direct analogue for geologic carbon sequestration

### Permalink

<https://escholarship.org/uc/item/1cm9k74r>

### Journal

Greenhouse Gases Science and Technology, 8(1)

### ISSN

2152-3878

### Author

Oldenburg, Curtis M

### Publication Date

2018-02-01

### DOI

10.1002/ghg.1761

Peer reviewed

# Revisiting underground gas storage as a direct analogue for geologic carbon sequestration



Curtis M. Oldenburg  
Energy Geosciences Division, Lawrence Berkeley National Laboratory, Berkeley,  
CA 94720, USA

Ever since the early 2000s, I have considered underground (natural) gas storage (UGS) to be a close industrial analogue for geologic carbon sequestration (GCS) as, for example, suggested in an early report by Benson et al.<sup>1</sup> Both UGS and GCS use wells to inject and store buoyant gas deep underground in the pore space of rock. Both UGS and GCS can use depleted hydrocarbon reservoirs or saline aquifers as storage complexes. Of course there are some differences between the two gases, e.g., the greater solubility of CO<sub>2</sub> in water relative to CH<sub>4</sub> (the primary natural gas component), greater density of super-critical CO<sub>2</sub> relative to CH<sub>4</sub>, and the flammability and buoyancy of CH<sub>4</sub> if leaked into the atmosphere. Furthermore, in UGS the natural gas is injected and withdrawn over various time scales rather than constantly injected as in GCS, creating differences in the needs for facility surface infrastructure, and strain on wells, wellheads, and surface flow lines. But overall, UGS seems to serve as a useful example of how large volumes of gas can be handled and stored underground.

Over the last two years, I have learned much more about UGS through work with my colleagues on various projects related to the 2015 Aliso Canyon incident. This incident began in late October 2015 as a natural gas leak from a casing rupture at a depth of approximately 1000 ft (300 m) in the deep (8700 ft, 2600 m) SS-25 well at the Aliso Canyon UGS facility near Los Angeles, California. (Although the ruptured casing has now been extracted from the well, the exact depth of the initial breach is still being investigated as the casing is examined by forensic experts as part of the root-cause analysis.) The leak evolved during early kill attempts into an unignited breach blowout. Wind blew the leaking gas into the nearby Porter Ranch neighborhood, leading to widespread health impacts potentially associated with mercaptan odorant and/or other components entrained in the natural gas. Several thousand households were evacuated.

Reliance on the casing alone for containment of gas created a single-point failure configuration

Numerous attempts to stop the gas flow by pumping dense fluids and solid particles into the well ('top kills') failed. In February 2016, a relief well boring intercepted the SS-25 well in the gas storage reservoir at a depth of approximately 8500 ft (2600 m). Dense fluid flowing from the relief boring into SS-25 stopped the gas flow ('bottom kill') ending the nearly four-month leak. The blowout is estimated to have released ~100 000 tons of natural gas into the atmosphere ([https://www.arb.ca.gov/research/aliso\\_canyon/aliso\\_canyon\\_methane\\_emissions-arb\\_final.pdf](https://www.arb.ca.gov/research/aliso_canyon/aliso_canyon_methane_emissions-arb_final.pdf)),<sup>2</sup> ~6% of the working gas capacity of the UGS reservoir.

With a better understanding of UGS in California in general and of the 2015 Aliso Canyon incident in particular, I am revisiting the status of UGS as an analogue for GCS. The main reason for questioning the analogue, at least in California but probably also in many other states, is that UGS has often been carried out using old repurposed wells that were operated in a way that provided only one barrier (the casing) between high-pressure gas and the environment. For instance, the casing in SS-25, which was regularly used for both injection and withdrawal, was over 70 years old at the time of the blowout.

Reliance on the casing alone for containment of natural gas created a single-point failure configuration. Standard underground injection wells, oil and gas wells, and GCS CO<sub>2</sub> injection wells are required to use at least two-point failure configurations (injection and production through tubing packed off inside the casing) that are much safer. In UGS wells in California, the space between the tubing and casing (the A-annulus) was regularly connected to the inside of the tubing just above the packer by either a sliding-sleeve valve or permanent openings. The reason for this was to utilize the large cross-section of the well for maximizing gas transfer rate. The downsides of this configuration are well known, specifically (i) full reliance is placed on a single casing wall, (ii) there is no 'dead' space between the tubing and casing to monitor for packer, tubing, or casing leakage, and (iii) complex openings that connect the space between the tubing and casing (A-annulus) to the inside of the tubing can thwart standard top-kill procedures.<sup>3</sup> I emphasize that new California state regulations prompted by the 2015 Aliso Canyon incident have now been put into place that prohibit the continued use of wells with single-point failure configurations, a change that will greatly reduce the likelihood of loss of containment from UGS wells going forward.

How is it that UGS in California was using wells with only one barrier for the last several decades? It turns out that UGS wells are excluded in the United States from the Environmental Protection Agency's (EPA's) Underground Injection Control (UIC) regulations. This point was mentioned – although not emphasized – in one early report influential to the GCS community<sup>1</sup> but it was specifically missed in another later influential report<sup>4</sup> and therefore may not be well known, especially within the international GCS community. In contrast, GCS in the United States is subject to UIC regulations that require at least two barriers, as do all other CO<sub>2</sub> injection regulations around the world to the best of my knowledge.

Another reason for revisiting the analogue between UGS and GCS is the different ways in which the facilities operate. In California, UGS involves injection and withdrawal for several different purposes that include (i) meeting seasonal peak heating demand (in winter), (ii) meeting seasonal peak electricity demand (for summer air conditioning), (iii) balancing daily load needs arising from intermittent renewables (solar and wind) that comprise a growing percentage of power to the electricity grid, and (iv) carrying out short-term (daily and even hourly) price arbitrage. The short-term injection and withdrawal processes in particular have no currently foreseen analogues in GCS. Yet short-term pressure and temperature swings impose more frequent and potentially hysteretic strain cycles on facility infrastructure such as wellheads, casing, and tubing, which increase likelihood of loss of containment, especially in older infrastructure.

In summary, increased understanding of UGS in California has led me to question the strength of the analogy between UGS and GCS. While some aspects are very similar and the overall long-term effectiveness of UGS provides an excellent point of reference for GCS, I believe that GCS as it is being developed and demonstrated currently will be significantly safer than UGS has been over the last century based on the UGS incidents that I have seen documented in various places, e.g., Evans.<sup>5</sup> The main reasons that I expect GCS to have vastly fewer loss of containment incidents on either a per well or per tonne of CO<sub>2</sub> injected basis are that (i) the wells used for injection will be modern built-for-purpose wells regulated by informed agencies, (ii) the GCS process mainly involves injection at nearly constant rates which places much less strain on wells and wellheads arising from pressure and temperature changes over time, and (iii) without withdrawals, GCS surface infrastructure will be simpler with less likelihood of failure than UGS surface infrastructure.

I encourage the GCS community to learn as much as possible from the UGS experience so that GCS can build on this prior injection experience to make GCS as safe and effective as possible.

**Curtis M. Oldenburg**

#### References

1. Benson SM, Hepple R, Apps J, Tsang CF and Lippmann M, *Lessons Learned from Natural and Industrial Analogues for Storage of Carbon Dioxide in Deep Geological Formations*. Lawrence Berkeley National Laboratory, Berkeley, CA (2002).
2. Conley S, Franco G, Faloona I, Blake DR, Peischl J and Ryerson TB, Methane emissions from the 2015 Aliso Canyon blowout in Los Angeles, CA. *Science* <https://doi.org/10.1126/science.aaf2348> (2016).
3. Pan L, Oldenburg CM, Freifeld BM and Jordan PD, Modeling the Aliso Canyon underground gas storage well blowout and kill operations using the coupled well-reservoir simulator T2Well. *J Petrol Sci Eng* **161**:158–174 (2018).
4. International Energy Agency Greenhouse Gas, *Safe Storage of CO<sub>2</sub>: Experiences from the Natural Gas Storage Industry*. R&D program. (2006).
5. Evans DJ, A review of underground fuel storage events and putting risk into perspective with other areas of the energy supply chain, in *Underground Gas Storage, Worldwide Experiences and Future Development in the UK and Europe* ed. by Evans DJ and Chadwick RJ. The Geological Society, London, pp. 173–216 (2009).