Long-Term Viability of Underground Natural Gas Storage in California

An Independent Review of Scientific and Technical Information

Chapter 1, Section 1.0
Introduction

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1.0 INTRODUCTION

1.0.1 Overview of Underground Natural Gas Storage in California

The general purpose of underground gas storage (UGS) is to meet varying demand for natural gas (methane, CH_4) over daily to seasonal time scales in the face of constant-rate gas production and limited pipeline transport capacity. In California, UGS is used to meet peak winter direct-use demands (home and business heating), to meet peak summer demands for electricity (e.g., air conditioning), to balance intermittent renewables (wind and solar), and to carry out price arbitrage (see Chapter 2 for complete details on the role of UGS in the California energy system). UGS is carried out in California by connecting underground storage reservoirs to the network of transmission pipelines that deliver natural gas from its sources in gas reservoirs throughout the western U.S., including local California natural gas reservoirs, to its customers in California.

The California UGS system in 2017 comprises 12 UGS facilities, four in southern California, seven in northern California, and one in central California, with a total capacity to store just under 400 Bcf of natural gas. The total amount of gas in the 12 UGS facilities is significantly higher than 400 Bcf because much of the gas in the storage reservoirs is cushion gas, which is essentially gas whose decompression provides the driving force for withdrawal of the last bit of working gas on any withdrawal cycle. The California UGS reservoirs have an average depth of ~5000 ft and are accessed by deep wells. At the depth of the reservoirs, natural gas is under high pressure (e.g., >1000 psi (~7 MPa) for most facilities). The handling and containment of high-pressure natural gas, which is highly flammable and explosive, entails risk. If a large surface loss-of-containment (LOC) incident occurs, fire and/or explosion are possible, with potentially catastrophic consequences for workers, the public, and the UGS infrastructure itself.

1.0.2 UGS Storage Operation Basics

Each UGS facility in California is a combination of surface and subsurface systems (as shown by the schematic in Figure 1.0-1) designed to inject, contain, and withdraw natural gas through wells that access the deep pore space of the storage reservoir. In the surface part of the system, UGS utilizes a pipeline (referred to here as the interconnect) to deliver and receive natural gas to and from the transmission pipeline. The boundary of the UGS facility is taken here as the junction of the interconnect to the transmission pipeline. The interconnect delivers gas to and receives gas from the compressors and gas processing facilities, respectively. These facilities are connected to the wells through what we refer to here as flowlines, which are typically relatively small-diameter pipelines. Note that we consider the wellheads to be both part of the surface infrastructure and part of the subsurface system. The reason for this duality is that wells are subject to hazards at the surface such as impacts by vehicles and landslides and flooding, and yet they are also integral parts of the well, which is primarily part of the subsurface system of containment for UGS. So the wellheads are at the intersection of surface and subsurface systems. Field lines connecting to the wellhead are components of the surface system.

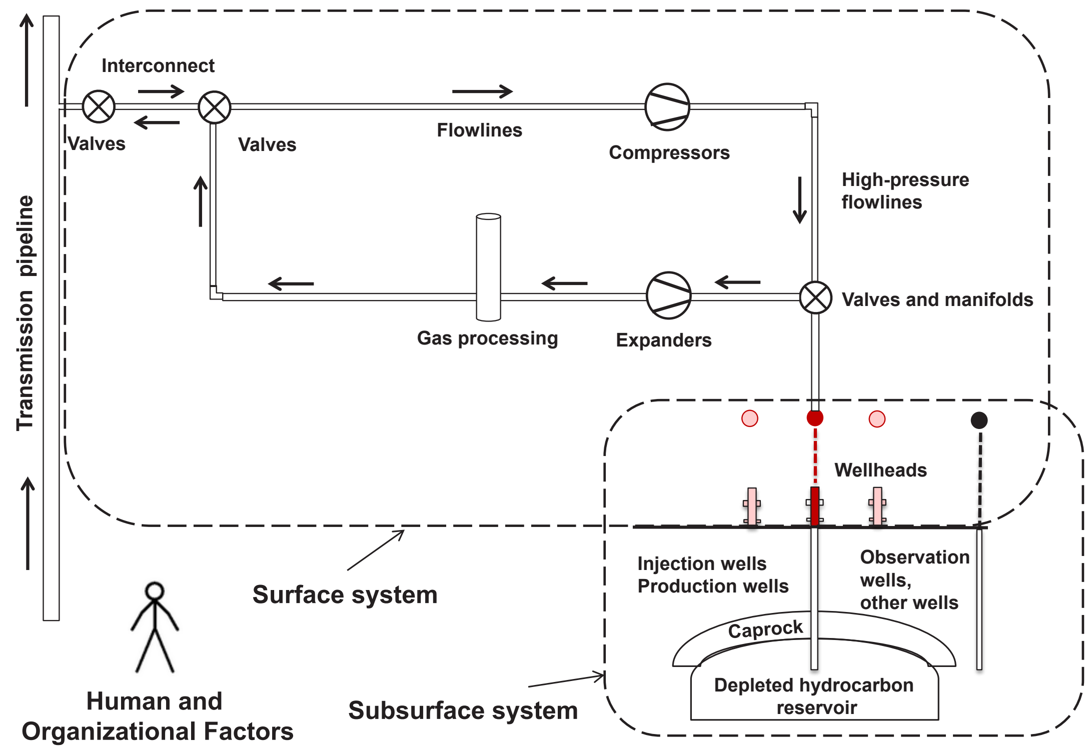

Figure 1.0-1. Simplified schematic of the main components of UGS facilities in California, showing examples of engineered surface components and the wells and geologic features comprising the subsurface system. Human and organizational factors play a critical role in control of both surface and subsurface systems.

Although transmission pipelines are referred to as high-pressure pipelines, gas normally must be compressed in order to be injected through the wells into the storage reservoir (typical pressures greater than 1,000 psi (7 MPa)). Upon withdrawal, gas is normally expanded to lower its pressure and must be processed (e.g., dehydrated) before delivery back to the transmission pipeline. Some processed natural gas may be utilized on-site for powering system components such as turbine compressors.

The subsurface part of UGS comprises the reservoir for storage, the associated deep aquifers that may be present to provide pressure support, the caprock (also referred to as seal) for keeping buoyant gas from flowing upward, the overburden which contributes to additional storage security, and the well and wellhead. Additional wells at UGS facilities may include observation or monitoring wells. Other wells not formally part of the UGS system may also be present, e.g., for oil production from reservoirs not connected to the gas storage reservoir. All wells connected to hydrocarbon reservoirs must be sealed to contain high-pressure gas or oil in the reservoirs. The wells connected to the high gas pressure in the storage reservoir must contain that pressure all the way to the wellhead, after which the surface infrastructure is relied on to contain the gas.

UGS reservoirs in California are all in depleted hydrocarbon reservoirs as described in Section 1.1. Following pressure depletion caused by long-term hydrocarbon production, the hydrocarbon reservoirs can be repressurized by injection of natural gas and repurposed as gas-storage reservoirs. Within the reservoir, natural gas pressure is generally maintained at or below the pressure exerted by water filling the pores of rock prior to the original production of the gas and oil. As such, pressure differentials between gas in the storage reservoir and water in the pores of the rock surrounding the reservoir are not particularly large. Nevertheless, gas does tend to rise in deep formations due to buoyancy. Upward gas migration is resisted by low caprock permeability and by capillary forces that tend to hold water in the small pores of the caprock at the expense of gas. This creates the so-called gas-entry pressure, which is a pressure threshold that must be exceeded in order for gas to displace water from the pores in a rock. Caprock is commonly a fine-grained clay-rich rock that has intrinsically low permeability but more importantly has a high gas-entry pressure, thereby creating a strong barrier to upward gas migration.

The human figure depicted in Figure 1.0-1 represents the human and organizational factors (HOFs) of UGS. Human managers, engineers, and technicians employed by the operating company, along with contractors, provide one component of the human factor element controlling both the surface and subsurface parts of the UGS system. Another part of the human factor component comprises the general public and the local population. In addition, operational practices are inevitably influenced by long- and short-term organizational and cultural factors present in the UGS operating company. Section 1.2.6 and a side bar in Section 1.6 elaborate further on HOF's and safety culture.

1.0.3 Overview of Chapter

In this chapter, we provide a review of the state of UGS in California in the context of the risks entailed by the practice of UGS, and how those risks can be managed and mitigated. Potential consequences arising from UGS failures, such as large-scale LOC from well blowouts, include threats to worker safety and loss-of-life, along with possible public health impacts in downwind populations from natural gas and associated chemical components from the reservoir, including odorants. Large and small flow-rate LOC of natural gas through wells, or leaky valves and seals, may be a concern for its effects on climate because methane is a powerful greenhouse gas, and subsurface leakage of reservoir gases and associated components is a concern for contamination of groundwater. In addition, failure of UGS for any reason can lead to its inability to provide gas to the energy network, a hazard to the stability and reliability of California's energy infrastructure.

This chapter (Chapter 1) consists of six separate sections that stand alone but are also integrated to describe the risk posed by UGS in California and the mitigation of this risk. The benefits and purposes served by UGS in California are covered in Chapter 2. We start in Section 1.1 with a summary of the characteristics of all of the UGS facilities in California. This description sets the stage for Section 1.2, which addresses the ways in which UGS can fail, e.g., resulting in natural gas (mostly methane (CH_4)) release, but also potentially releases of other entrained fluids and chemical compounds to the environment, including by well blowout, and the likelihood and consequences of UGS system failures. Section 1.3 addresses the question of loss of capacity of UGS facilities as they age and/or as they suffer storage integrity failures or near-misses of failures. In Section 1.4, we discuss the health and safety hazards related to UGS, including for the general public as well as for workers. In Section 1.5, we present what is known about emissions from UGS facilities of methane in the context of its role as a greenhouse gas (GHG). Finally, in Section 1.6, we discuss risk management, practices to mitigate UGS risks, and the new regulations proposed by the state that are aimed at increasing safety and reliability of UGS in California. The six sections that follow are based on available information and data, the completeness of which varied. As a result, the sections vary in their degree of detail and completeness.

The scientific issues studied within each of the six sections are summarized in a number of findings, conclusions, and recommendations. Findings are facts found by the science team that could be documented or referenced and that have importance to our study. Conclusions are deductions made based on findings (facts). And recommendations are statements that recommend what an entity should do as a result of our findings and conclusions. The most relevant conclusions and recommendations of this chapter were selected by the Steering Committee to be included in the Executive Summary. These selected findings and recommendations are indicated below by their reference number in the Executive Summary. Note that the final conclusions and recommendations included in the Executive Summary were developed in an iterative process based on in-depth discussion within the Steering Committee along with continued consultation with the science team. Final responsibility for these conclusions and recommendations lies with the Steering Committee.

1.0.4 Definitions

Reviewing UGS in the context of hazard and risk entails use of terminology from the fields of oil and gas, gas storage, and risk assessment. In order to make it convenient for the reader to understand terminology in this chapter, we provide up front the following brief table of definitions. Additional terms and acronyms that may not be familiar to all readers are defined in a glossary at the end of the chapter. It is important to note that many of the terms in Table 1.0-1 are defined for use in this report in the context of risk assessment and UGS, and may have more general meanings in common usage.

Table 1.0-1. Definitions of key terms.

Key Terms	**Definitions**
Accident scenario	Failure scenario, sometimes called an "accident sequence".
Bcf	One billion (109) cubic feet normally referred to as a gas volume. (1 Bcf CH4 = 19,255 tonnes CH4).
Blowdown	Intentional venting of gas from a well or surface component.
Blowout	The uncontrolled flow of gas, liquids, or solids (or a mixture thereof) from a well into the aboveground environment.
Breach blowout	The uncontrolled flow of gas, liquids, or solids (or a mixture thereof) out of fractures or cavities in the ground, the flow of fluid from which originates from well failure.
Capillary trapping	The exclusion of one fluid from entering a rock pore due to the surface tension of its interface with the fluid already in the pore being higher than the pressure difference between the two. Generally, the smaller the pore, the greater the buoyancy of the fluid that cannot enter the pore.
Caprock	The rock overlying the reservoir that prevents buoyant fluids of interest, such as stored gas, from migrating upward out of the reservoir. This can be either via capillary trapping or low permeability (although these typically occur simultaneously because they are both a result of small pore size). Synonymous with seal.
Condition	Measured or observed status, state or property of a system, e.g., the pressure or temperature, the composition of the gas stream, etc.
Consequence	Impact, or quantified negative effect of a failure scenario
Cushion gas	Natural gas in the reservoir that is not withdrawn and that serves to drive out the last bit of working gas on any withdrawal cycle. A.k.a. base gas.
Depleted reservoir	Hydrocarbon reservoir in which the pressure or mass of reserve has been lowered by production to the point that further production of oil or gas is sub-economic.
Dispersion	Dilution and mixing effects associated with transport, e.g., dispersion of CH4 occurs as it is transported by wind.
Event	An occurrence that is relatively short-lived and that affects the safety or operation of a system: e.g., an earthquake, a pipeline rupture, and a breach blowout are all events bearing on UGS safety.
Failure scenario	Sequence of events surrounding a component or system malfunction with resulting negative effects or costs.
Feature	A component or characteristic of a system: e.g., the caprock, wells, and flowlines are some of the features comprising a UGS system.
FEP-scenario approach	Features, Events, and Processes (FEPs), a method to aid in generating a complete and accurate set of failure scenarios.
Hazard	Potential cause of negative effects associated with a component or system failure.
Incident	An event or occurrence affecting a UGS facility involving any or all of the following: Gas release significant enough to warrant reporting, injury/loss of life, damage to property or infrastructure.
Injection	Delivery of fluid (liquid or gas) from the ground surface to the reservoir via wells.
Leakage	Gas or related fluid migration or flow out of the storage system into the environment (subsurface or above ground). Largely synonymous with loss-of-containment.
Likelihood	Probability per year or quantitative or semi-quantitative chance (or expected frequency) of occurrence of the failure scenario
Loss-of-containment (LOC)	Unplanned release to the environment (subsurface or above ground) of gas or related fluid. LOC incidents refer to significant losses of containment of stored gas, i.e., significant enough that it warranted reporting.
Off-normal	Condition characterized by deviation from standard operational or shut-in status, e.g., gas leakage in a system designed to contain gas, plugs in lines that are intended to transport gas, excessively high or low pressure in flowlines, tanks, well tubing or annuli.

Key Terms	Definitions
Plant	In the context of a UGS facility, the plant is the part of the facility with surface infrastructure consisting of any one or all of components such as compressors, gas processing units, electricity generation units, or control room and/or operator office space.
Pool	A reservoir as defined by the California Division of Oil, Gas, and Geothermal Resources. As used in practice by the agency though, a pool may consist geologically of more than one reservoir, such as different sandstone strata within a formation.
Pore	The void space within a rock that can be occupied by a fluid. In a sedimentary rock, this space is that which is not occupied by the original sediments and any material chemically precipitated after deposition of the sediments (cementation).
Process	A long-term or slow change in the system relevant to performance: e.g., corrosion of steel, cement degradation, or sand production are some examples of processes relevant to UGS performance.
Production	Extraction/delivery of fluid (liquid or gas) from the reservoir to the ground surface via a well for the purpose of recovering fluids from a natural accumulation.
Reservoir	A contiguous volume of rock with permeability sufficient to inject and produce or withdraw the fluid of interest at a rate that makes doing so economic.
Risk endpoint	Value to be protected (e.g., health, safety, containment, non-degradation).
Risk	Consequence × Likelihood
Seal	The rock overlying the reservoir that prevents buoyant fluids of interest, such as stored gas, from migrating upward out of the reservoir. This can be either via capillary trapping or low permeability (although these typically occur simultaneously because they are both a result of small pore size). Synonymous with caprock.
Seismic hazard	Likelihood of an earthquake of a given magnitude on a given fault (or within a given area) within a given time.
Spud	To begin drilling a wellbore into the ground.
Subsurface blowout	The uncontrolled flow of gas, liquids, or solids (or a mixture thereof) from a well into the subsurface environment.
Threat	Qualitative potential for a failure scenario to affect something (synonym here for hazard).
Withdrawal	Extraction/delivery of fluid (liquid or gas) from storage in a reservoir to the ground surface via wells.

1.1 CHARACTERISTICS OF CALIFORNIA UNDERGROUND GAS STORAGE FACILITIES

1.1.1 Abstract

We have identified and searched multiple databases and other public sources to gather information to characterize the state of underground gas storage (UGS) in California. Gas injection via gas storage wells occurred in 13 facilities in California in 2015 prior to the Aliso Canyon well blowout ("well blowouts" in California are defined as "the uncontrolled flow of well fluids and/or formation fluids from the well"; Hauser and Guerard, 1993). Gas injection via storage wells ceased in the Montebello facility at the end of 2016 with the approval of the operator's application to inactivate the injection permit. Three of the four remaining facilities in southern California store gas in depleted oil reservoirs. The remaining facility, along with the one in central and seven in northern California, store natural gas in