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Underground Gas Storage in China

Developing a World Class Program

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Summary

China is setting a path to aggressively increase underground gas storage (UGS) capacity in the next two decades. Though UGS brings benefits to the gas supply system, including operational flexibility and efficiency, there can be significant detrimental impacts to human health, and safety and the environment when things go wrong. This has been evidenced first-hand in the United States (where some of the oldest and largest UGS facilities are located), most recently through the disaster at Aliso Canyon in California.

As China draws upon well-established technical and regulatory guidance addressing UGS facilities, it is critical that China develops and institutes a management framework throughout all phases of UGS operation, from planning and construction through operation and, ultimately, closure. This report outlines a management framework that works in concert with existing leading technical practices and provides insight into how technical excellence, regulatory oversight, and internal procedures and culture interact to reduce risk to health, safety and the environment. Properly developed and deployed, the framework outlined in this report will help protect against a broad spectrum of vulnerabilities related to UGS.

Properly developed and put in place, this framework will help protect against a broad spectrum of vulnerabilities related to UGS.

This framework is presented as four cornerstones of a premier UGS program.

1. Proper risk management
2. A health, safety and environment (HSE) management system
3. Technically competent operations, and
4. Informed and enforceable regulations

Given the rapid expansion of natural gas use in China and the concurrent need to increase UGS capacity, it is incumbent upon stakeholders to do this right the first time – relying on sound science, competent management, and accurate information to avoid having to respond when things go wrong. This framework is designed to prevent foreseeable and predictable problems and could be used as an overarching reference document by Chinese operators and policymakers as they develop their guidelines and management programs prior to the planned expansion of UGS capacity.

China's Initiative to Increase Underground Gas Storage Capacity

Natural gas demand in China has undergone rapid growth as the country replaces high-polluting coal with cleaner burning natural gas to address pressing air pollution challenges. Natural gas supply in China is now met by a number of sources including importation (via liquefied or pipeline) and expansion of domestic production. To balance gas supply and address supply bottlenecks (both geographical and seasonal), China is initiating a new wave of UGS projects. Compared with the United States, which has some of the world's oldest and largest UGS facilities that date back more than 100 years, China is a relative newcomer to UGS with only about 20 years of experience.

Globally, UGS construction and operational technologies are mature, and existing technical and regulatory guidance around can help industry and regulators design and operate UGS facilities (see American Petroleum Institute (API) Recommended Practices 1170 and 1171; American National Standards Institute (ANSI) Standard EN 1918; the Interstate Oil and Gas Compact Commission and Ground Water Protection Council's "Underground Gas Storage Regulatory Considerations"; and Canadian Standards Association's (CSA) "Storage of Hydrocarbons in Underground Formations").

But mere adherence to leading technical practices may not be sufficient to prevent serious health, safety and environmental threats. This is evidenced by the recent Aliso Canyon disaster, which triggered the amendment of California's UGS regulation and prompted U.S. Pipeline and Hazardous Materials Safety Administration to adopt minimum uniform federal safety standards to reinforce state efforts. For China to develop a world class UGS program, Chinese operators and regulators must work together to create a seamless management framework interwoven with a competent management and informed regulatory program, that includes the technical expertise found in existing resources, but also includes systems and processes for systemically and continuously reducing risk to human health, safety and the environment.

In 2017, China accounted for 30 percent of the increase in global gas demand[1] and is projected to drive a quarter of the rise in global demand by 2040[2]. Today, China imports nearly 40 percent of its natural gas, concentrating supply points in border and port areas. At the same time, China's domestic gas consumers have become increasingly diversified in both users and location, creating challenges to meet demand during high use periods[3]. Prior to 2000, chemical and industrial sectors accounted for more than 80 percent of gas use. Today, over 50 percent of gas is used by power and residential/commercial sectors, and the trend continues upward[4]. This shift results in rising seasonal supply/demand imbalances, which highlight the need for a more substantial gas storage and transportation network. The distances between natural gas sources (both imports and domestic production) and increasingly numerous and diverse users present additional challenges to both siting of gas storage facilities and pipeline transport to and from these facilities.

China's UGS development is still at a relatively early stage. Though the first UGS site in China was built in 1969, large-scale storage projects did not occur until 1999 after the completion of China's first long-distance gas pipeline that transported gas from Shaanxi province to Beijing[5]. The associated UGS development played an important role in addressing seasonable demand fluctuation in the capital region. Currently, there are 25 underground storage facilities in China (compared to around 400 in the United States). The China National Petroleum Corporation (CNPC) manages 23 facilitates, and the China Petroleum and Chemical Corporation (Sinopec) operates two. At the end of 2017, China's storage capacity could only cover slightly over three percent of the country's annual consumption, far below the international average of 10-12 percent[6].

The government established targets for storage expansion to fill this gap. By 2020, national oil companies are required to have storage capacity equivalent to 10 percent of their annual contracted sales, city distributors' storage must be able to meet five percent of their supplies, and local governments must ensure three-day storage for their jurisdictions[7]. The national oil companies are also urged to open up their facilities to third-party access. The goal is to increase the national working gas storage capacity from 11.7 billion cubic meters (bcm) in 2017[8] to 14.8 bcm by 2020, and to 35 bcm by 2030[9], about 4.1 percent and 5.8 percent of the total expected annual consumption respectively[10]. In response to these signals, both CNPC and Sinopec are accelerating UGS planning and construction and are building large-scale underground facilities, at least doubling the current facilities in only 10 years. CNPC plans to build 23 additional facilities before 2030. Sinopec plans to build the country's largest UGS cluster in central China[11].

In ramping up its UGS infrastructure to manage the increasing use of natural gas in all sectors of the economy, China faces a number of logistical and engineering challenges, including:

- Geographic distance between sources of natural gas (domestic production and imports) and population centers and other user locations,
- Mandated rapid increase of storage volumes that requires relatively quick decisions to be made on location, storage volumes at specific locations, and completion of design, construction, and operations,
- Challenging geological conditions.

Figure1 - China's Gas Network

Source: Cedigaz

Most of the depleted oil and gas production fields that could be repurposed for gas storage are in the northeast, central and west regions. But market demand is greatest along the eastern seaboard, where most underground formations are salt caverns and aquifers12,13 and are challenging for gas storage.

Currently most UGS in China occurs in depleted oil and gas fields (23 of the current 25 storage facilities). The majority of these oil and gas fields are of low permeability, with depths typically below 2,500 meters with some exceeding 4,500 meters. In comparison, 95 percent of the world's UGS facilities are shallower than 2,500 meters14. Moreover, the depths at the potential salt cavern facilities are generally in formations 500 meters deeper than the typical cavern UGS15. Generally speaking, deeper cavern UGS is more expensive and technically riskier than shallower cavern UGS.

Notwithstanding the technical and operational challenges outlines above, and given China's commitment to transition to much more natural gas versus coal in their energy portfolio, the use of underground natural gas storage delivers considerable benefits to the natural gas value chain. The primary purpose of underground natural gas storage is to secure supply and price stability. There are a number of events that can cause serious perturbations in the supply and demand balance, such as weather, accidents, natural disasters and geopolitical fluctuations. A well planned and well executed network of underground gas storage facilities could provide a desired leveling buffer that insures adequate energy delivery and price stability.

Cornerstones of a World Class Program

A leak at an underground gas storage facility in California -- shown here with an infrared camera, emitted over 100,000 tonnes of methane into the atmosphere in 2015.

Improperly managed systems can present considerable risks to the environment, and human health and safety even if good technical resources are used to design and construct UGS. Three recent accidents in the United States illustrate the importance of having a robust UGS framework in place and properly implemented.

In 2001, natural gas from a depleted reservoir storage facility near Hutchinson, Kansas migrated several kilometers through subsurface conduits to the city's downtown, where explosions killed two people, destroyed two buildings, and caused geyser-like spouts of gas and water around the city before authorities were able to plug the leaking wells and vent the gas that had built up under the city[16].

In 2004, a salt cavern storage facility in Moss Bluff, Texas, released 170 million cubic meters of gas in only six days, prompting an evacuation of all residents in a five-kilometer radius. The gas flare was over 300 meters tall and visible up to 30 kilometers away[17].

Finally, in late 2015, the Aliso Canyon depleted reservoir gas storage facility, the largest in the western United States, lost containment and leaked for four months before it could be brought under control, leading to the evacuation of 11,000 people from an adjacent neighborhood[18]. The leak (142 million cubic meters) was nearly the size of the one in Moss Bluff, but the gas was vented instead of flared – the release of 100,000 tonnes of methane was equivalent to the annual carbon emissions of nearly 600,000 cars in the United States.[19]

All three of these incidents were likely preventable through enhanced construction, inspection and maintenance protocols, and all three states launched extensive gas storage regulatory program revisions as a result.

The remaining discussion outlines four cornerstones of a premier UGS management framework that will help protect against a broad spectrum of vulnerabilities. The first three cornerstones are targeted at industry, with regulatory input, as appropriate. The fourth is targeted equally at industry and regulators.

- Proper risk management;
- A health, safety, and environment (HSE) management system;
- Technically competent operations; and
- Informed and enforceable regulations.

If faithfully executed, a framework that includes these four cornerstones will reduce accidents, enhance public health and safety, provide cost and operational efficiencies, significantly reduce uncertainty, protect the environment (through reduced methane emissions and other air pollutants, and by preventing pollution of the surface and water systems), prevent waste, conserve natural resources, and fulfill broad energy policies. These cornerstones must have their own individual policies, processes, and procedures that stem from a commitment from uppermost leadership through all staff levels. Each of these is important and distinct from the other.

- Policy drives why an organization does what it does. It is rule- and intent- driven.
- Process describes what an organization does in support of its policies.
- Procedures are how an organization actually performs what it does.

Procedures are very specific in nature and ensure tasks are executed consistently and correctly. In addition to policy, process and procedure, the four cornerstones have to be fully and seamlessly integrated with each other. For example, consider the interconnectedness of drilling, completion, and production. Though a drilling team may actually construct a well in record time and at a historically low cost, the resulting product may be in such a physical state that it cannot be completed as planned. So, to properly integrate the four cornerstones, the organization must insist the teams work together and remain open to making adjustments and modifications so that each complements the other to deliver a product that works well for all stakeholders.

Cornerstone 1 - Robust Risk Management Program

A robust risk management program is fundamental to any operation and, if done properly, will incorporate a number of principles necessary for the organization to consistently and efficiently achieve its goals. A well designed program will: create value to the organization, be an integral part of all organizational processes, address a full range of uncertainty, and be systematic and structured. It will also be based on the most currently available information, be tailored to the specific organization and tasks, include all stakeholders, assimilate human and cultural factors (both internal and external), be iterative and dynamic and be continually improved upon.

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- assimilate human and cultural factors (both internal and external)
- be iterative and dynamic – process of continual improvement.

A framework to develop a risk management program must be established jointly by organizational executives and staff and its mandate must be understood and accepted at all all levels of the organization. A strong, easily understood and executed policy is the starting point. At a minimum, the policy should address operational accountability and responsibility, key performance indicators (KPIs), identify and allocate sufficient resources, provide the training and skills necessary to achieve organization performance goals and include social and corporate responsibility and accountability. This framework can be further detailed in four parts.

The first part entails formally documenting the organization's culture (for example the organization's appetite for risk). This includes developing, as needed, processes and procedures that integrate risk management into all facets of the organization's operations (including financial, legal, administrative, etc.), ensuring all aspects of resource allocation (time, training, skills, financial resources, IT support) are available, and establishing document management systems that incorporate record retention requirements. In addition, a well-established internal and external communication and reporting network must be established that includes continual program monitoring and review. Finally a process to efficiently ensure continual improvement must be established.

The second part entails properly executing the program. A number of processes have to be embedded in the culture for specific operational and business purposes. The organization must first identify all sources, events, causes and consequences of risk during risk identification and then conduct a thorough analysis that yields an understanding of likelihoods and consequences of those risks. Armed with this information, the organization can make informed decisions about risk evaluation (outcome comparisons) and risk treatment (options for managing risk such as avoidance or environmental modification to mitigate the risk).

The third part of the program is follow-up. This includes continual monitoring, review, and recordkeeping for the life of the project as well as ensuring continual improvement of the program based on experience and learning.

Fourth and finally, a key aspect of risk management is determining the acceptable levels of risk for the organization's various activities and the level of risk reduction the organization should pursue. Not all risks can be reduced to zero. Working with the regulator, however, organizations should adopt a standard such as "As Low As Reasonably Practicable" for risk reduction, which entails a cost-benefit analysis for risk-control protocols[20].

Cornerstone 2 - Comprehensive HSE Management System

An HSE (health, safety and environmental) management system is a systematic approach and set of principles by which an organization efficiently manages risk with respect to industrial health and hygiene, the safety of its employees, contractors and public, and the integrity of the environment within which it operates. Each organization may choose some elements very specific and tailored to its needs, but there are several fundamental functions that are required for effective HSE management.

First and foremost, there must be a policy statement and/or letter of commitment that originates at the executive level and that addresses plainly why the organization considers a commitment to worker and public safety and well-being and the protection of the environment an organizational priority. It should view this commitment as a cooperative effort among itself, the affected public, all contractors and other stakeholders that participate in the organization's efforts. As with other organizational endeavors, adequate resources (time, training, skilled professionals, capital, etc.), open and transparent communication networks, and employee involvement are all essential to a respected and functioning HSE governance structure.

Many organizations operating at a high level of efficiency and accomplishment will have clearly defined and understood organizational charts that communicate responsibilities and accountability, as well as relevant KPIs that not only measure performance against predetermined objectives, but also present meaningful proactive measures for management and staff. These goals and objectives are often deployed in a balanced scorecard format. They are frequently put into "SMART" goal formats: specific, measurable, actionable, relevant and time-bound.

Competent HSE management systems include at least seven important programs.

1. **Hazard analysis** – This includes hazard identification, risk assessment (to include likelihood and severity), correction (elimination, substitution, engineering and administrative controls and personal protective devices) and nonconformance (regulations, policies and other requirements) identification.
2. **Incident investigation** - While this may not always include an exhaustive root cause analysis, it must incorporate a process for all incidents (not just accidents) to be investigated with corrective action and lessons learned as a result. The goal of this process is to mitigate the risk of future occurrence. Investigations should be communicated to all relevant business units in a timely manner.
3. **Emergency preparedness and response** - The organization should have well established

[20] See, e.g., United Kingdom Health and Safety Executive, Risk Management: ALARP at a glance, available at http://www.hse.gov.uk/risk/theory/alarpglance.htm

procedures to identify, prevent, prepare for, and respond to emergency situations. Emergency response plans define roles and responsibilities, authority structures, resource requirements, communication (external and internal) training, and drills, and should include all relevant stakeholders, especially first responders and adjacent community leaders. These plans should be frequently and regularly reviewed and updated with the best available information.

4. **Training** - Training can be segmented into several categories such as new hires, certifications, job-specific or competency. It is critical that the organization train to a level of demonstrated competency, not just performing trainings to fulfill a periodic requirement. Training programs must clearly identify training responsibilities and accurate recordkeeping.
5. **Contractor management program** - It is important to employ contractors that are technically competent and devoted to the same level of HSE commitment as the organization. While cost-saving is important, it is more important that shortcuts to reduce costs do not result in sacrificing safety, health and environmental protection.
6. **Management review and/or management of change** - This program is fundamental to the organization's ability to improve and learn from mistakes and changing environments. It should be well documented and taken seriously throughout the organization. All levels of leadership and management associated with all levels of staff should participate.
7. **Document and data control/management and retention** - The program will have to identify documents to be controlled, define the review and update specifications, protect against damage, define retention times, identify document approval protocols, and assure documents are kept up-to-date and remain pertinent throughout the organization.

Cornerstone 3 - Sound Technical Practices

In coordination with management practices previously discussed, there are four main facets of physically locating and operating UGS facilities:

1. Planning and design,
2. Construction,
3. Operation, and
4. Closure.

During the planning/design phase, a number of factors determine which strategies and tactical considerations are relevant. At the least, supply and demand play a key role, especially with respect to the need for supply and price stability as well as facility size and location. Many decisions are driven by specific jurisdictional considerations, their goals and objectives, and important energy policy. Obviously, the organization must closely consider geographical and geological constraints in concert with needed infrastructure to support the facility and distribute its product.

The facility construction phase encompasses all aspects and activities of constructing the physical plant. From a high level, this includes:

- Surface selection;
- Site preparation, including collaboration with adjacent land users;
- Drilling injection and monitoring wells (or previous well conversions);
- Completion;
- Installation of surface treating, operating and monitoring equipment; and
- Connection to the transport infrastructure.

Associated with this is a plethora of activities to select qualified vendors and contractors, collaborate with supply chain for the best available materials and services, develop and execute all the associated procedures, and coordinate several reservoir and mechanical integrity tests with regulatory and organizational professionals. Each step of these activities must be vetted through the risk management program (Cornerstone 1) and performed in a manner that adheres to all aspects of the organization's HSE management system (Cornerstone 2). Over the years, industry has developed many proven leading practices that can be applied generally and adapted to local nuances. Indeed, there is no shortage of these practices and professionals around the world with vast experience and skill with whom to consult.

The operation phase follows immediately after facility construction and integration into the available infrastructure. The major issues here involve:

- Regular testing for facility mechanical integrity;
- Monitoring for reservoir integrity, day-to-day operations, injection and production volumes;
- Adhering to regulations and internal guidelines pertaining to mass balance;
- Periodic reporting of key operational metrics;
- Well workovers and other facility maintenance;
- Regularly scheduled drills to test emergency preparedness and response;
- Training; and
- Record retention.

The fourth and final phase is closure of an individual well or an entire facility, whether temporarily or permanently. All too often, this phase is not given the due attention that other operational phases are given. However, the status of an aging well or facility in an abandoned state may have a significant impact on the subsurface and surface for decades to come if not handled properly. The closure phase could be broken into four categories.

1. Temporary Shut In. From time to time, a well or wells may need to be removed from service (shut in) for maintenance or to address temporary alterations in supply and demand. In this case, it usually is sufficient to shut-in and monitor that the well is properly isolated from the UGS facility and subsurface strata.
2. Temporary Abandonment. All jurisdictions will have regulations designed to address temporary abandonment safely, which entails securing the well or wells from the UGS facility and subsurface strata. There is usually a time constraint imposed upon wells in this status. Also, there will be regular status reports required for submission to management and regulatory bodies.
3. Permanent Abandonment. Permanent abandonment is desired when the well or facility is no longer needed or has failed to secure and maintain mechanical integrity. In this case, specific procedures must be followed to permanently seal the well or wells from subsurface strata and to positively negate possible exposure to subsurface fluids. This is typically accomplished through the use of mechanical plugs and cement placed across predetermined intervals in the wellbore.
4. Site Restoration. Various regulations exist to drive this process. In the best case, all surface facilities are removed and disposed of properly or reused, and the surface is returned to its original condition or some pre-determined or agreed-upon state. The paths this phase may take are quite varied but nevertheless very important if health, safety, and the environment are to be protected long-term.

Cornerstone 4 - Informed and Enforceable Regulatory Framework

The final cornerstone draws from technical and management expertise and incorporates the reality that people (whether individually or as groups) perform at a higher level when there is a means to check and verify that defined criteria are met. An informed and enforceable regulatory framework emerges in large part by agencies being well-versed in the latest technologies and field-proven leading practices with respect to risk management, HSE and technical criteria.

Accordingly, organizational executives must build and nurture a culture wherein rules and regulations are followed because individuals and teams “want to” versus “have to” follow them. There is a clear and profound difference. At the same time, external regulatory agencies and their staff operate best within a culture of collaboration with industry toward maximizing compliance with rules and policies while at the same time recognizing the importance of identifying noncompliance with appropriate enforcement and corrective action.

An organization’s internal regulatory teams are in a very unique position to provide invaluable help to achieving important organizational performance metrics. These teams should be staffed with competent professionals who receive the latest training and information.

To maximize effectiveness, these groups need a clear mission that consists of the following:

- Providing assistance in preparing required permits and compliance reports,
- Aiding collaboration with outside regulatory bodies,
- Assisting operational units interpret and comply with rules and regulations, and
- Offering assistance with upgrading regulations to be more in alignment with the latest best practices and technologies.

External regulatory agencies should have a mission statement that includes conserving natural resources, protecting correlative rights, prevention of waste, and protecting public health, safety and the environment. Every effort should be made at the national, provincial and local levels to allocate required resources to assist these agencies in successfully completing their mission.

Key regulatory principles to practice include:

- Collaboration with other agencies and regulators, industry, government objectives and public stakeholders; and
- Consistency in regulatory response through efficient and transparent processes resulting in fairness to all individuals and organizations and timely and efficient outcomes.

A key regulatory function is to establish levels of acceptable risk for various facilities and operational functions related to UGS. Tied to the risk management planning process articulated in Cornerstone 1, the regulator should work with industry participants to reduce risks to the level the regulator determines acceptable for the local context. One common heuristic for doing so, referenced earlier, is “As Low As Reasonably Practicable.”But whether the regulator adopts this or another standard, it is important for the regulator to articulate a standard to which operators can plan toward.

Regulators must be as informed as possible regarding the latest technologies and leading practices and use this information to develop the best, up-to-date regulations possible; be outcome oriented consistent with their regulatory objectives/mission; and undertake proportionate decisions based upon risk assessment and industry responses. It is important that regulatory bodies be transparent in their activities, decisions, and processes.

In order to establish effective regulatory enforcement, several leading practices are required.

- Regulatory enforcement and inspections should be evidence-based as well as measurement-based.
- Enforcement should be based upon risk and be proportionate to the individual response. This can range from an organization truly trying to be in compliance to one that simply refuses to be compliant.
- Inspection functions should be well coordinated and designed to minimize, to the extent reasonable, burdens on the organization being inspected.
- Enforcement function must operate in an environment of transparency and professionalism, with a sharp focus on outcomes that support its mission.
- Rules and regulations should be clear and understandable so that organizations are confident in their rule interpretation and subsequent compliance efforts. Rules and regulations cannot be arbitrary in nature and must be well supported by established practice and experience.
- Regulators should consider market forces that may influence compliance and enforcement. In response to commodity prices and new technologies, industry practices often change frequently and dramatically. Regulators should accommodate this in their planning and execution.

This framework is designed to prevent foreseeable and predictable problems

An informed and enforceable regulatory framework is vital to an organization and industry, whether it is internal to the organization or an external agency, and one size never fits all. There are usually important local and regional nuances that must be recognized and respected. Development of effective regulations is a collaborative effort among the regulator, industry, public, professional societies, and environmental organizations. Done properly, collaboration can become seamless, as each entity seeks to drive to their own good performance and realizes they work best together in a spirit of cooperation.

Opportunity for Development of a World Class UGS Program

These four cornerstones could serve as a useful reference for gas storage operators and regulators in China in developing and implementing a world class underground gas storage program that meets China's energy needs and protects health, safety, and the environment. Technical information and sound engineering are necessary, but insufficient. A fully integrated management and regulatory program is necessary, too. Given the rapid expansion of natural gas use in China and the concurrent need to increase UGS capacity, it is incumbent upon stakeholders to do this right the first time – relying on sound science, competent management, and accurate information to avoid having to respond when things go wrong. This framework is designed to prevent foreseeable and predictable problems and could be used as an overarching reference document by Chinese operators and policymakers as they develop their guidelines and management programs prior to the planned expansion of UGS capacity.

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