CMG

De-risking CCS Projects:

Risks, Regulations & Site Selection

Your CCS Learning Journey

This is Part 2 of the three-part series on Carbon Capture and Storage (CCS). In this edition, you'll learn about the risks associated with CO_2 storage, the regulatory frameworks that govern projects and the processes for site selection.

Next, continue your journey with:
Part 3 – Making CCS Work: Economics, optimization strategies, and CMG's CCS solutions.

If you haven't already, start with the preceding Ebook:
Part 1 – The Science of Safe Carbon Storage

Together, these three volumes provide a complete foundation, from the science to the strategies, for building successful CCS projects.

What You Will Learn

Introduction: The critical role of de-risking

Carbon Capture and Storage (CCS) depends on more than science alone. Even with strong trapping mechanisms and proven geologies, projects face risks that can compromise containment and long-term success. Geological variability, chemical reactions, mechanical stresses, and well integrity all shape outcomes. Beyond the subsurface, projects must address transport risks and operate under regulatory frameworks that demand transparency.

This ebook examines the risks associated with CO_2 storage, the regulatory frameworks that govern projects, and the processes for site selection. It highlights geological, geochemical, geomechanical, and wellbore risks, explains how sites are screened and characterized, and outlines the importance of transport, monitoring, and compliance in building secure and credible CCS projects.

1. Understanding the risks of storage

Subsurface uncertainties (geological risks)

Geological risk arises from an incomplete understanding of the reservoir and its sealing formations. Even with seismic imaging, core sampling, and well logs, uncertainties remain about faults, fractures, and heterogeneity.

Risks include:

- **Caprock failure**: If injection pressures exceed fracture gradients, CO_2 may breach the seal.
- **Fault reactivation**: CO_2 can migrate along conductive faults or fractures.
- **Reservoir heterogeneity**: Variations in porosity and permeability can lead to uneven plume migration.
- **Lateral leakage**: If boundaries are poorly defined, CO_2 may escape laterally into formations not intended for storage.

Mitigation strategies:

- Select sites with thick, regionally continuous caprocks such as shales or evaporites.
- Conduct detailed seismic surveys to map faults and fractures.
- Build reservoir simulation models that account for heterogeneity and injectivity variation.
- Limit injection pressures to safe margins below fracture thresholds.

Fluid-rock interactions (geochemical risks)

Injected CO_2 dissolves in brine to form carbonic acid, lowering pH and driving mineral reactions. These reactions can have both positive and negative effects on containment.

Risks include:

- **Mineral dissolution**: Carbonates dissolve, increasing porosity and weakening seals.
- **Secondary precipitation**: Silica or clays may precipitate, reducing injectivity.
- **Brine chemistry changes**: Mobilization of trace metals or organic compounds may create environmental concerns.
- **Altered wettability**: CO_2-brine-rock interactions can shift wetting properties, impacting capillary trapping.

Mitigation strategies:

- Laboratory experiments to measure reaction kinetics under reservoir conditions.
- Geochemical modeling of brine-rock-CO_2 systems to forecast long-term impacts.
- Monitoring of produced water chemistry during injection to identify changes early.

Stability under stress (geomechanical risks)

Injecting CO_2 raises reservoir pressure and changes stress fields. These changes may affect both the reservoir and the overlying caprock.

Risks include:

- **Fracture propagation**: New fractures may open if pressure exceeds fracture gradients.
- **Fault reactivation**: Increased pore pressure reduces effective stress, potentially reactivating pre-existing faults.
- **Caprock deformation**: Excessive strain may reduce seal integrity.
- **Induced seismicity**: Stress redistribution can trigger seismic events.

Mitigation strategies:

- Conduct geomechanical modeling to simulate stress changes.
- Identify critically stressed faults through borehole image logs and seismic inversion.
- Apply pressure management strategies, including controlled injection rates and brine extraction where necessary.

The challenge of legacy wells (wellbore risks)

Wellbores are among the most significant potential leakage pathways. Abandoned or poorly constructed wells may bypass geological seals, providing direct conduits to the surface.

Risks include:

- **Cement degradation**: Reaction with carbonic acid reduces cement strength and bonding.
- **Casing corrosion**: Steel casings corrode in CO_2-rich brines, accelerating over decades.
- **Incomplete abandonment**: Older wells may lack proper plugs, continuous cement, or zonal isolation.
- **Pressure transmission**: Wells may act as conduits that rapidly transmit pressure to shallow formations.

Mitigation strategies:

- Develop a complete inventory of wells within the area of review.
- Conduct mechanical integrity testing (MIT) on accessible wells.
- Apply remediation methods such as squeeze cementing, casing patches, or complete re-abandonment.
- Require modern abandonment practices for all new wells, including multi-barrier cement plugs and verified integrity testing.

Risk interaction and cumulative effects

These four categories of risk do not act in isolation. For example, geomechanical stress can open faults that also increase geochemical reactivity by exposing fresh mineral surfaces. Legacy wells may amplify pressure transmission, increasing the likelihood of caprock failure.

For this reason, risk assessment must be integrated across disciplines, combining geological, geochemical, geomechanical, and well integrity modeling into a unified framework.

2. How CCS projects take shape

CCS Projects reduce uncertainty by moving through structured phases before injection. Each stage adds knowledge and lowers risk.

Here is the 7 stage process:

1. Project Framing

This stage sets the foundation for the entire project. The goal is not to pick a site yet, but to define the scope, CO_2 capture targets, and key performance criteria. Technical, economic, regulatory, and community considerations are documented to ensure all stakeholders are aligned. Clear framing reduces early uncertainties and provides a structured decision-making framework for every step that follows.

2. Regional Screening

Broad geological regions are narrowed down to basins or sub-basins with realistic potential for CO_2 storage. This screening relies on existing datasets such as geological maps, basin-scale seismic, and exploration records. Key filters include sufficient depth, high-quality reservoirs, effective sealing formations, and tectonic stability. Proximity to large CO_2 sources and infrastructure is also factored in, ensuring resources are not wasted on unsuitable areas.

3. Site Screening

Within the promising basins, more focused evaluations identify candidate storage sites. Higher-resolution seismic surveys, well logs, and available core data are analyzed to assess reservoir quality, thickness, porosity, permeability, and seal integrity. Environmental and social factors such as land use, accessibility, and nearby infrastructure are also considered. This stage bridges broad regional assessments with detailed site studies, creating a refined shortlist of viable options.

4. Site Selection

Candidate sites are ranked and prioritized based on geological suitability, technical feasibility, and economic viability. Sites closer to CO_2 sources or existing infrastructure often score higher, as do those with minimal environmental or community conflicts. This phase ensures that resources are concentrated on the most promising storage prospects, balancing technical, social, and economic considerations.

CO2 Storage Slide Selection Process

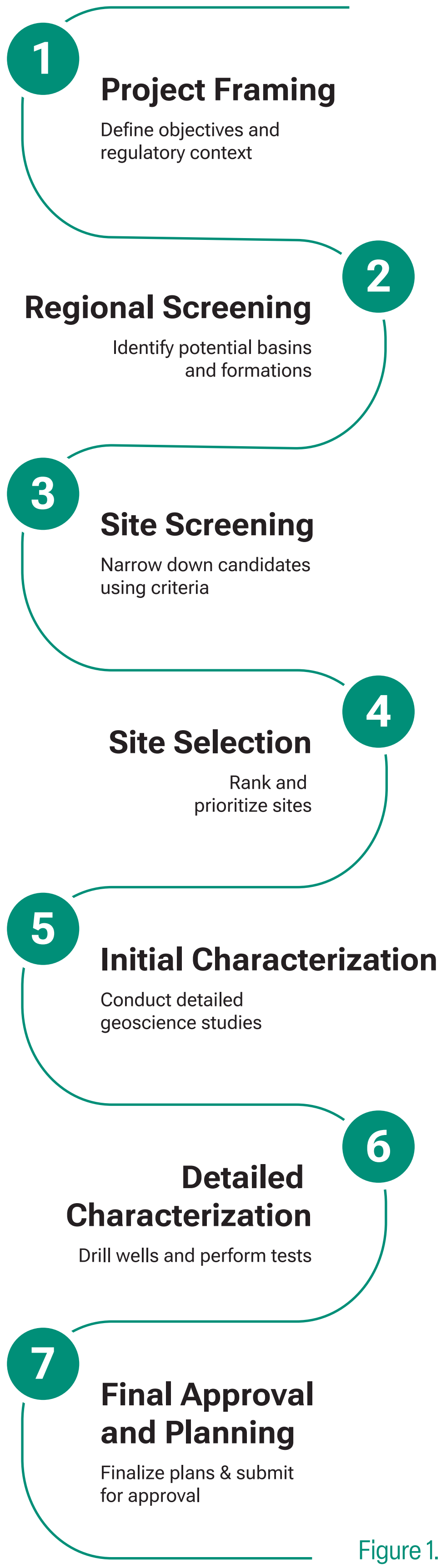


Figure 1. CO_2 Storage Site Selection Process

5. Initial Characterization

Target sites undergo preliminary data acquisition and testing to validate their potential. Tools such as 3D seismic surveys help map subsurface structures, while stratigraphic wells provide direct reservoir and seal samples. Laboratory testing of cores and fluids refines estimates of porosity, permeability, injectivity, and storage capacity. Early geomechanical and geochemical analyses establish safe operating limits and form the baseline for future monitoring.

6. Detailed Characterization

This phase reduces uncertainty to the lowest possible level before injection begins. Advanced data acquisition is carried out, including additional wells, high-resolution 3D or 4D seismic, and extended injection or flow tests. Geological models are refined, and integrated numerical simulations (using platforms like CMG's CoFlow) predict long-term injectivity, storage capacity, and plume migration. These detailed studies optimize well placement, validate seal performance, and establish definitive monitoring baselines.

7. Final Approval & Planning

All technical, economic, environmental, and regulatory results are consolidated into a comprehensive development plan. This includes finalized well locations, injection strategies, monitoring programs, and risk management measures. Environmental impact assessments and permitting are completed, with regulatory and community approvals secured. At this stage, the project is fully de-risked and ready for safe, efficient, and transparent long-term CO_2 storage operations.

3. Moving CO_2 safely

Transporting CO_2 from source to storage site introduces technical challenges. Most projects use high-pressure pipelines, though ships, trucks, and rail can be applied in specific regions.

Key risks include:

- **Phase stability**: CO_2 must be kept above critical pressure to prevent two-phase flow.
- **Water contamination**: Even small amounts of water form carbonic acid, which corrodes steel.
- **Impurities**: Components like H_2S, SO_2, and O_2 accelerate corrosion or alter phase behavior, requiring removal before transport.

Safe transport relies on continuous monitoring of pressure, composition, and flow, supported by rigorous maintenance.

4. Managing flow and phase changes

Flow assurance in CCS projects is complex because CO_2 changes behavior under pressure and temperature shifts.

- **Joule-Thomson cooling**: Rapid pressure drops lower the temperature, which may form dry ice.
- **Hydrate formation**: CO_2 combines with water to form crystalline hydrates at high pressure and low temperature, blocking flow.
- **Two-phase flow**: Below critical pressure, CO_2 separates into liquid and gas, complicating injectivity.

Mitigation strategies include:

- Maintaining CO_2 above critical pressure in pipelines and injection wells.
- Dehydrating CO_2 streams to eliminate free water.
- Heating wellbores or using inhibitors where hydrate risks are highest.
- Using thermodynamic models to anticipate behavior under site-specific conditions.

By managing these risks, operators maintain stable injectivity and avoid flow restrictions.

5. Staying compliant and monitoring storage

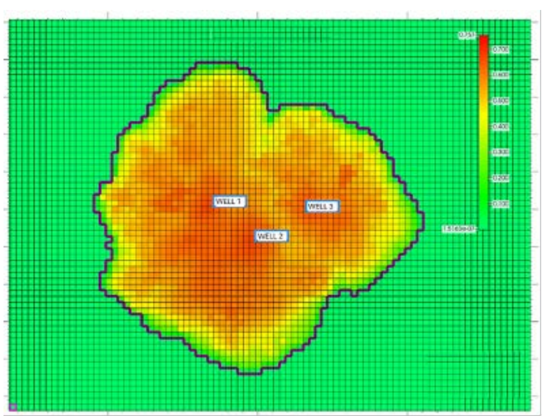
CCS projects operate under strict regulatory oversight. Compliance begins with permits and environmental assessments, but continues through the life of the project.

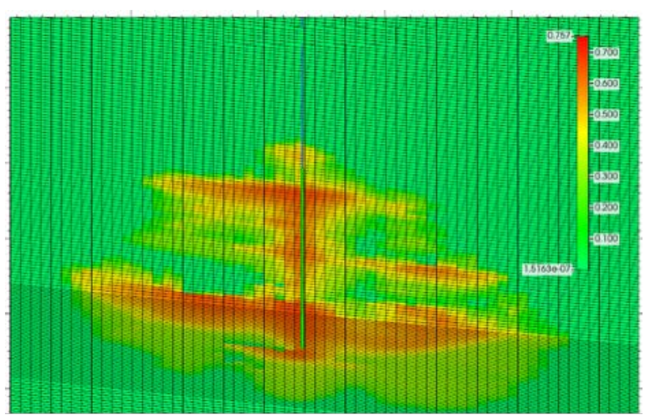
Any inadequacies in existing wells located within the designated Area of Review (AoR) must be identified and addressed through appropriate corrective measures. The AoR encompasses regions where the migration of the injected CO_2 and resulting pressure changes may affect native pore fluids.

Monitoring programs track plume migration, reservoir pressure, and containment. Tools include:

- **Seismic surveys**: Time-lapse imaging verifies plume location and seal integrity.
- **Downhole gauges**: Sensors measure pressure and temperature changes.
- **Soil and groundwater sampling**: Detects leakage near the surface.
- **Surface and satellite monitoring**: Identifies microseismic activity or ground deformation.

Monitoring continues long after the injection ends. Many jurisdictions require decades of post-injection surveillance until the reservoir has stabilized. This long-term data not only satisfies regulators but also builds confidence with stakeholders.





6. From risk to resilience

CCS projects succeed when risks are identified, evaluated, and managed at every stage. Geological, geochemical, geomechanical, and wellbore factors must be addressed before injection begins. Transport and flow assurance add further layers of complexity, and compliance provides accountability.

De-risking is not a one-time step but an ongoing process woven into site selection, planning, transport, and monitoring. Projects move from uncertainty to resilience when this approach is applied consistently.

7. Next step: making CCS work

The science explains how CO_2 is stored. De-risking shows how projects can be executed safely. The next challenge is to make CCS viable at scale by addressing economics, optimization, and the tools that help operators plan effectively.

These themes form the focus of our next volume: **Ebook 3 – Making CCS Work: Economics, Optimization & CMG Solutions.**

Learn more about how to de-risk your CCS project at

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