Title:

Repurposing Depleted Hydrocarbon Assets for Subsurface Carbon Sequestration: Mechanical Integrity and Geochemical Risks

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Abstract

Depleted oil and gas fields are frequently cited as the lowest-risk candidates for deep geological carbon storage due to the availability of seismic surveys, well log data, and verified structural trapping integrity. However, injecting supercritical carbon dioxide introduces severe mechanical and geochemical stresses that distinguish carbon sequestration from standard water injection or secondary recovery projects. This article reviews the primary failure pathways associated with legacy wellbore cement degradation, reservoir cooling stresses, and caprock geochemical dissolution, emphasizing why brownfield sites demand stringent re-entry and verification protocols before injection begins.

1. The Legacy Well Problem

The greatest asset of a depleted hydrocarbon field—its dense history of drilled wellbores—is simultaneously its primary environmental liability. In fields developed decades ago, primary cementing was completed using materials and practices never intended to withstand prolonged exposure to acidic, carbonic fluids. When supercritical carbon dioxide dissolves in formation brines, it lowers the local pH, dissolving Portland cement matrices via leaching of calcium hydroxide and destabilizing silicate hydrates. A single improperly abandoned appraisal well penetrating the storage complex can serve as an open conduit back to shallow drinking aquifers or the surface.

2. Thermo-Hydro-Mechanical Stresses During Injection

Supercritical carbon dioxide is typically injected at temperatures considerably lower than the deep reservoir formation temperature. This thermal contrast induces localized cooling near the injector wellbore, triggering rock shrinkage and reducing the horizontal stress field. If surface injection pressures are not throttled to account for this thermo-elastic weakening, micro-fractures can initiate along the caprock boundary well below the original tectonic fracture gradient of the pristine reservoir.

3. Reservoir Monitoring and Containment Longevity

Ensuring long-term storage viability requires permanent surface and subsurface monitoring arrays. Traditional 4D surface seismic offers coarse tracking of the expanding gas plume, but lacks the vertical resolution to catch thin-channel migration along faulted seals. Integrating distributed fiber-optic acoustic and temperature sensing across active and observation wells provides continuous surveillance of plume movement, allowing field engineers to identify localized channel development long before fluid migration threatens seal integrity.

References

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