Considerations in Developing QM for EOR Storage.

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Type	Storage Only- Saline	EOR with Incremental Storage
Land	Greenfield	Brownfield-already impacted by oil industry operations
CO_2 Management	CO_2 injection	CO_2 injection, production, recycle
Pressure Build-up Risk	Potential for large areas of pressure increase; pressure management may be needed	Pressure management is goal of EOR
CO_2 Trapping	Inferred trapping mechanisms	Demonstrated trapping
Solubility of CO_2 in Formation Fluid	CO_2 weakly soluble formation brine	High solubility of CO_2 in oil
Subsurface Information density	Few wells: sparse information	Many wells: subsurface well known
Mechanical Integrity/ Risk of Well Failure	Few wells, carefully drilled, cased and cemented	Many existing wells, some in unacceptable condition. Expense to remedy: identify, and re-enter to plug/repair
Pore space access	Variable by state; evolving	Existing legal framework
Revenues to offset CO_2 capture cost	No	Yes
Monitoring & verification, accounting (MVA)	MVA must be based on comprehensive geologic study.	Existing reservoir production and surveillance knowledge contributes to development of MVA; integrity of existing wells in the field a principal leakage concern.
Public Acceptance	Unknown.	Likely to be good. Public familiar / comfortable with oil production

- Application of a saline QM approach to EOR may not result in most effective use of resources and could inadvertently result in unnecessary barriers to commercial EOR storage development, and focus effort in wrong places to assure storage integrity.

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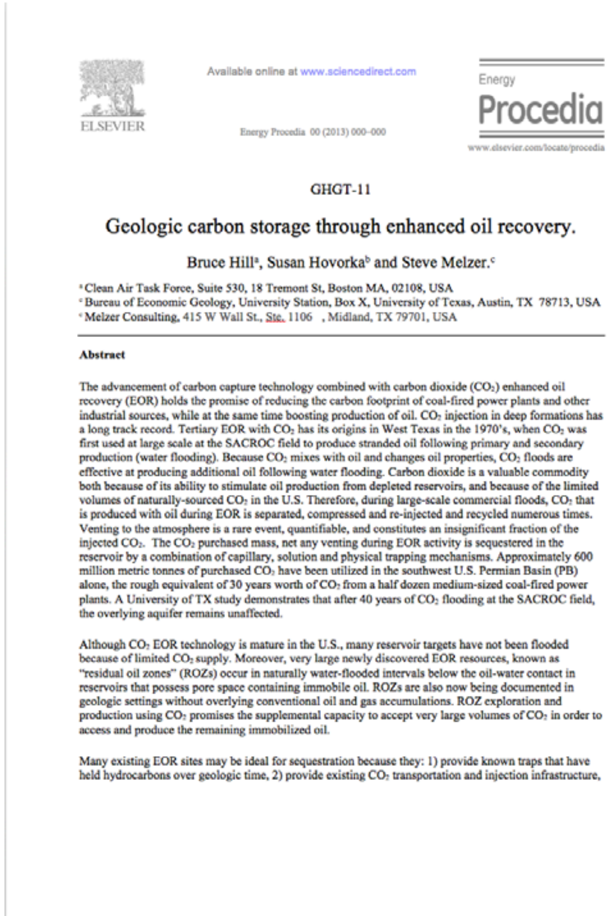

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Geologic carbon storage through enhanced oil recovery.

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Abstract

The advancement of carbon capture technology combined with carbon dioxide (CO_2) enhanced oil recovery (EOR) holds the promise of reducing the carbon footprint of coal-fired power plants and other industrial sources, while at the same time boosting production of oil. CO_2 injection in deep formations has a long track record. Tertiary EOR with CO_2 has its origins in West Texas in the 1970's, when CO_2 was first used at large scale at the SACROC field to produce stranded oil following primary and secondary production (water flooding). Because CO_2 mixes with oil and changes oil properties, CO_2 floods are effective at producing additional oil following water flooding. Carbon dioxide is a valuable commodity both because of its ability to stimulate oil production from depleted reservoirs, and because of the limited volumes of naturally-sourced CO_2 in the U.S. Therefore, during large-scale commercial floods, CO_2 that is produced with oil during EOR is separated, compressed and re-injected and recycled numerous times. Venting to the atmosphere is a rare event, quantifiable, and constitutes an insignificant fraction of the injected CO_2. The CO_2 purchased mass, net any venting during EOR activity is sequestered in the reservoir by a combination of capillary, solution and physical trapping mechanisms. Approximately 600 million metric tonnes of purchased CO_2 have been utilized in the southwest U.S. Permian Basin (PB) alone, the rough equivalent of 30 years worth of CO_2 from a half dozen medium-sized coal-fired power plants. A University of TX study demonstrates that after 40 years of CO_2 flooding at the SACROC field, the overlying aquifer remains unaffected.

Although CO_2 EOR technology is mature in the U.S., many reservoir targets have not been flooded because of limited CO_2 supply. Moreover, very large newly discovered EOR resources, known as "residual oil zones" (ROZs) occur in naturally water-flooded intervals below the oil-water contact in reservoirs that possess pore space containing immobile oil. ROZs are also now being documented in geologic settings without overlying conventional oil and gas accumulations. ROZ exploration and production using CO_2 promises the supplemental capacity to accept very large volumes of CO_2 in order to access and produce the remaining immobilized oil.

Many existing EOR sites may be ideal for sequestration because they: 1) provide known traps that have held hydrocarbons over geologic time, 2) provide existing CO_2 transportation and injection infrastructure,

Basis for EOR Storage

- 4 decades of CO_2 know how.
- Known trap containing HCs for millions of years, known injectivity, production volumes.
- Plume and pressure control through patterned injection and withdrawal of oil and brine.
- Recycle means virtually all of the purchased/injected CO_2 remains in system and not lost to atmosphere, with exception of small volumes of vented/ fugitives. Operators' experience: Progressive CO_2 trapped in the subsurface with recycle.
- "Incidental" or "associated" storage is the only acceptable carbon storage approach for today's production companies. Industry has no interest in "packing it to the brim."
- "Stacked" brine storage in associated saline intervals is a hypothetical, but could be useful in old fields taking advantage of the existing infrastructure.
- Production of Residual Oil Zones (e.g. K-M' TW. X Tall Cotton), including "greenfields" (no overlying main pay zone) can be treated like EOR-storage projects.

Focal points for risk reduction and CO_2 containment from atmosphere

- Prevention--Site selection criteria should be adopted to screen out risky EOR projects for storage purposes - e.g. fields with fractured cap rock, fields with too many unknown legacy wells, or those fields with legacy wells which have been poorly plugged / old fields with casing pulled for steel reuse.

- Legacy well integrity -- All wells in projected CO_2 management area should be investigated (robust p&a for abandoned wells; for repurposed wells, integrity of materials such as casing & cement) and remedied where needed.

- How to handle edge-of-field CO_2 migration or "leakage" from the EOR complex (beyond a lease where CO_2 can no longer be tracked); use of water curtains and their termination at end of a project. Accounting and CO_2 containment and production sharing agreements between companies?

- Closure--No EOR projects have been closed yet. How is project closure defined? Production block by production block? One advantage in EOR is that while patterns may close, fields remain open, so some form of surveillance might easily continue.

- CO_2 withdrawal / moving CO_2 to another part of field, pipeline, or another project should be incorporated in accounting methodology.

- In the case of change of field ownership, how to handle accounting, transfer of MRV, reporting responsibilities, accounting for already-stored CO_2.

Some Thoughts on Monitoring and Accounting

- Monitoring should be leak-hypothesis based, in conjunction with initial risk analysis.
- Data collected under an agreement with operators could provide a foundation for CO2 verification. E.g. Injection/ fluid production data & pattern balance. (NOTE** Avoid conflating oil production and total fluid production.)
- Overlaps in "next generation" EOR and monitoring methods (e.g. new patterns, more wells, instrumented observation wells, downhole sensors, zone-by-zone flow tests to manage and control the CO_2 flood) mean that sophisticated operators may employ reservoir surveillance methods that could double as verification.
- Possible approach--tracking “pattern balance” of injectors and producers (Ideal would be near 1:1 injection/recovery of all injected ***<u>fluids</u>*** *(not oil).*
- Baseline monitoring in brownfields may be challenging. Katherine Romanak's method (see previous QM workshop) illustrates useful approach where leakage to aquifer or atmosphere is suspected.
- Simple methods such as routine surficial well observations will be very helpful in catching smaller well integrity failures and should be a part of all QM...But a regular "whack a mole" approach is not adequate and should raise questions about the viability of a field for CO2 containment.
- “Above zone monitoring interval” (AZMI) may useful for many projects—especially where there is an extensive, laterally communicative zone above a containment zone or cap rock.

Highlighting Key Points

- EOR storage has a different, although overlapping, set of considerations relative to saline storage.
- EOR can be advantageous for storage of CO2, but operators are currently only interested in incidental storage. Accounting for recycle may be difficult and most straightforward approach may be: purchased- losses.
- Well integrity is primary concern. Initial site screening should avoid fields with unacceptable remedial cost and leakage risk.
- The concept of closure may be different than saline. Approach should consider the long term nature of EOR. Storage projects will likely close block-by-block. Any closure monitoring requirements should be leak-hypothesis based.
- Mining of data should be considered a core component of proving up storage. The burden should be on the operator to help develop an approach that fits the field/ project.
- Hard to have all the answers. Geology is always unique to each project. No cookie cutters. Program should learn/adapt by doing.