Presentation Outline

**Saline Aquifer Storage Overview**
- Motivation and Opportunities in California
- Advantages and Disadvantages Relative to Oilfield Storage

**Reservoir Characterization and Safe Injection Operations**
- Assessing Storage Capacity
- Assessing Sealing Characteristics
- Assessing and Mitigating Risks
- Appropriate Operating Parameters and Monitoring

**Sample Opportunities in San Joaquin Basin and LA Basin**

**Discussion**
CO2 Injection and Storage in Saline Aquifers
By Michael S. Bruno, PhD, PE
Terralog Technologies USA, Inc.

Status of Sedimentary Basins in California

Saline Formation Capacity

Estimated CO₂ storage capacities for ten largest sedimentary basins in California

Source: WESTCARB
Advantages Relative to EOR or Storage in Depleted O&G Fields:

1. Geographically much more pervasive throughout California
2. Much higher storage capacity
3. Fewer old/existing wells resulting in lower leakage risk
4. Limited impact on existing O&G production
5. Longer term operation relative to EOR (less likely to produce/cycle CO2)

Disadvantages Relative to EOR or Storage in Depleted O&G Fields:

1. Limited geologic data requires more extensive characterization
2. Limited economic incentive (relative to EOR)
3. Generally requires greater reliance on solubility trapping
4. Less common, fewer analogs, more challenging public outreach
CO2 storage in saline aquifers (and depleted O&G fields) requires EPA underground injection permit (Class I, Class V, or Class VI)

CO2 injection for enhanced oil recovery requires CA DOGGR injection permit (Class II)
After injection in the subsurface, the CO$_2$ will become trapped within the pore space of the rock formation through three primary storage mechanisms:

- **Structural storage;** (requires appropriate geology)
- **Solubility storage; and,** (requires sufficient time)
- **Mineral storage.** (requires appropriate lithology/chemistry and sufficient time)
Supercritical CO2 less dense than formation water and will rise due to buoyancy.

Several Years Time

CO2 Saturated water slightly more dense than formation water, and will eventually drop over time.
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Movie – Simulation 01 – Gas Saturation
CO2 Injection and Storage in Saline Aquifers

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a. Carbonate reef with closure for gas storage

b. Channel sand of limited length
c. Stratigraphic trap for gas storage development

d. Isolated zones of high porosity for storage
Optimum Storage Zones Located Beneath Alternating Seals (shale layers) and Sinks (sand layers)
Map and cross-section of typical turbidite deposition
(Henderson, 1987)
Two well model for dipping injection
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Gas saturation

Injection Rate: 1MM mt/yr
Injection Duration: 5 years
Shale permeability: 1mD
Salt: 3%

T = 5 years

T = 30 years
Movie – Simulation 07 – Gas Saturation
Ideal Geology for Storage of CO2 in Saline Aquifers (in order of effectiveness)

1. Well Defined Effective Structural Trap

2. Multiple Alternating Sand-Shale Sequences

3. Thick, Deep Storage Interval (bottom injection)
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Depth

Hydrostatic Gradient
~ 0.43 psi/ft

Min horizontal stress
~ 0.7 psi/ft

Optimum Injection Pressure
~ 0.5 psi/ft
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Saline Sub-basins in Southern San Joaquin Valley
**CO2 Injection and Storage in Saline Aquifers**

By Michael S. Bruno, PhD, PE
Terralog Technologies USA, Inc.

### Sample Saline Reservoir Storage Capacity Estimates for Southern San Joaquin Valley

#### Maricopa Sub-basin

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<thead>
<tr>
<th>Formation / Zone</th>
<th>Depth (ft)</th>
<th>Thickness (ft)</th>
<th>Area (E6 ft²)</th>
<th>Porosity (%)</th>
<th>Pore Vol (ft³)</th>
<th>Liq CO₂ (1000 kg)</th>
<th>1000 kg at 5% Saturation</th>
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#### Buena Vista Lake Sub-basin

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#### South Buttonwillow Sub-basin

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CO2 Injection and Storage in Saline Aquifers

By Michael S. Bruno, PhD, PE
Terralog Technologies USA, Inc.

Saline Sub-basins in Los Angeles County
CO2 Injection and Storage in Saline Aquifers
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## CO2 Injection and Storage in Saline Aquifers

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Terralog Technologies USA, Inc.

### Sample Saline Reservoir Storage Capacity Estimates for Los Angeles Basin

<table>
<thead>
<tr>
<th>Area</th>
<th>Potential Pore Vol (ft³)</th>
<th>Potential Pore Vol (m³)</th>
<th>Capacity (1000 kg at 5% saturation)</th>
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<td>Wilmington Graben</td>
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<td>Central Trough</td>
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<td>San Gabriel Valley</td>
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# CO2 Injection and Storage in Saline Aquifers

By Michael S. Bruno, PhD, PE
Terralog Technologies USA, Inc.

## Carson Refinery

**Type Log:** Composite Column

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- *Frio* Zone: F1, F0, F, H, K, G, G4, G5, G6
- *Ranger* Zone: F1, F0, F, H, K, G, G4, G5, G6
- *Upper Terminal* Zone: HK1, HK2, HK3, HPG, HK5, J, Y4K, Z, WA
- *Lower Terminal* Zone: AA, AB, AC, AD, AD1
- *Union Pacific* Zone: AC, AF, AI, AK1, AR, AL, AL1, AM
- *Ford* Zone: AO, AO1, AR, AR1, AL, AL2, AV, AR, AY, AY1, AZ
- *San Pedro* Zone: JF, KF
- *Base of fresh water*
The Los Angeles Basin presents a unique combination of great need and great opportunity for large scale geologic storage of CO2.

In part due to its significant population, and in part due to its historical and geologic setting as one of the most prolific oil and gas producing basins in the United States, the region is home to more than a dozen major power plants and oil refineries which produce more than 5 million metric tons of fossil fuel related CO2 emissions each year.

Furthermore, there are several natural gas storage reservoir in the basin, providing analogs and empirical evidence of long-term safe storage.
More than 3000 feet thickness of Pliocene and Miocene formations are present in the large Wilmington Graben directly offshore the Los Angeles and Long Beach Harbor area, at appropriate depth for CO2 sequestration (about 3000 to 7000 ft).

This zone is easily accessible yet geologically isolated from the nearby Wilmington Oilfield and onshore area, reducing communication risk and public risk.
CO2 Injection and Storage in Saline Aquifers

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North Graben Stratigraphy - DOE Project Formation Evaluation and Test Well #1

- 9 5/8" - 47lb L80 BTC casing
- 3 1/2" tubing to be installed
- 8 5/8" x 3 ½" Injection
- Packer @ 4900'
- WL Re-entry guide @ 4910'
- Downhole temp & press sensors
- Equivalent SFI#2 perf zone
- Perf 5090-5110'
- PBTD = not available

TD = 5430' MD; 5382' TVD
## CO2 Injection and Storage in Saline Aquifers

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### North Graben Stratigraphy - CLA Demonstration Project
Test Well

<table>
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<tr>
<th>Top from sea level [m]</th>
<th>Bottom from sea level [m]</th>
<th>Thickness [m]</th>
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Summary and Discussion:

1. Significant Saline Aquifer Storage Capacity in California
2. Significant Storage Capacity Within LA Basin (near industrial sources)
3. Most require further characterization and evaluation
4. Limited commercial incentive for CO2 storage in saline aquifer (particularly for intermediate scale projects)
5. Current regulatory regime complex, but not insurmountable
6. To date there have been no large-scale saline injection projects in California, and none currently in regulatory queue
7. Incentives should be developed for intermediate scale project (100,000 to 500,000 tons/yr) to demonstrate and evaluate the technology prior to larger scale operations.