Characterization of Pliocene and Miocene Formations in the Wilmington Graben, Offshore Los Angeles, for Large-Scale Geologic Storage of CO$_2$*

William E. Childers$^1$

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Abstract

The Los Angeles Basin presents a unique and special combination of high need and significant opportunity for large-scale geologic storage of CO$_2$. Terralog Technologies USA, Inc. was selected by the Department of Energy to manage a research project with the objective to characterize Pliocene and Miocene sediments within the Wilmington Graben, located offshore Los Angeles, for high-volume CO$_2$ sequestration. These sediments are suspected to span more than 5000 feet of vertical interval, with an estimated capacity to store more than 50 million metric tons of CO$_2$.

The Wilmington Graben is situated between the Palos Verdes and the THUMS-Huntington Beach faults, both of which act as sealing faults. While geologically isolated from the onshore area, thus reducing migration and communication risks, the graben remains easily accessible via directional drilling from the existing onshore oil and gas infrastructure. These Pliocene and Miocene sediments, primarily saline aquifers, have not been fully characterized.

To accurately evaluate and quantify sediments within the Wilmington Graben, we have drilled the first of 3 characterization wells. A complete suite of wireline logs, core samples and reservoir data were acquired as a result. We have also mapped the Wilmington Graben, using previously drilled well logs and seismic data, new and old. A CO$_2$ gas migration model has begun simulating the injection of 1 million metric ton per year of CO$_2$. In addition, we have identified the top industrial sources of CO$_2$ emissions in the Los Angeles Basin. To complement this effort, potential geologic sinks and pipeline infrastructure for transporting CO$_2$ from sources to sinks are also being identified.

Website

Characterization of Pliocene and Miocene Formations in the Wilmington Graben, Offshore Los Angeles, for Large-Scale Geologic Storage of CO₂

Bill Childers
Terralog Technologies USA, Inc

1. Project Background and Motivation
2. Project Plan, Status and Accomplishments
3. Next Steps
• Prolific oil & gas producing basins; Thick sediments.

• Home to numerous large power plants, oil refineries which produce more than 5 MMT of CO\textsubscript{2} emissions each year

• Precedence for gas storage throughout basin

• Significant need and opportunity for large-scale geologic storage of CO\textsubscript{2}
Los Angeles Basin Geology

• Contains massive sand & shale interbeds within the Pliocene and Miocene

• Provides excellent traps for oil & gas

• Contains several billion-barrel oil fields, e.g., Wilmington Oil Field (> 2 billion barrels produced to date)

• Contains 6 large-scale underground gas storage fields in the same age sediments (Operated by So Cal Gas Co. for over 50 years).

• Demonstrated both the storage potential & security of these formations for CO₂ sequestration if properly characterized and selected.
Why Wilmington Graben

- It is impractical to site a large-scale CO$_2$ storage project onshore beneath LA due to large population & complex land ownership.

- >3000ft thick of the same Pliocene and Miocene sediments are present in the Wilmington Graben, at approx. 3000-7000ft depth for CO$_2$ sequestration.

- This zone is easily accessible but geologically isolated from the nearby Wilmington Oilfield and the onshore area, thereby reducing communication and public risks.
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1) Improved evaluation and interpretation of existing 2D and 3D seismic data;

2) Acquisition and interpretation of additional 2D seismic lines;

3) Detailed log evaluation of existing exploration wells in the area;

4) Drilling and coring three new evaluation wells into the Graben (Pliocene and Miocene) and/or on the landward side of the THUMS-HB fault

5) Development of 3D geologic models, geomechanical models, and CO$_2$ injection and migration models for the region.

6) Analysis of industrial sources (top 20 in the LA Basin)

7) Engineering study of existing and new pipeline systems to transport CO$_2$ from significant local sources to sequestration sites (transport infrastructure study)

8) Risk analysis (include well integrity, induced and natural seismicity)
Existing 2D and 3D Seismic Data Prior to Project

- Existing 2D seismic data
- Existing 3D seismic data
- Data Gap Area
- Line 84
Efforts to Better Characterize Pliocene & Miocene for high-volume CO$_2$ Storage include

1) Improved evaluation and interpretation of existing 2D and 3D seismic data;

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Shot Point Map for 175km of New Seismic Lines
California State University, Long Beach provided the Seismic Boat and Equipment
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Exploratory Well Locations
Catalina Schist, Top Basement structure map
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<table>
<thead>
<tr>
<th>MD (ft)</th>
<th>Lithology</th>
<th>Formation</th>
<th>Age</th>
<th>Seismic Marker</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5000</td>
<td></td>
<td>Repetto</td>
<td>Pliocene</td>
<td>Tmd ~250ft from Top</td>
</tr>
<tr>
<td>-4000</td>
<td></td>
<td>Repetto</td>
<td>Pliocene</td>
<td></td>
</tr>
<tr>
<td>-3000</td>
<td></td>
<td>Upper Repetto Unconformity</td>
<td>Pliocene</td>
<td></td>
</tr>
<tr>
<td>-2000</td>
<td></td>
<td>Pico</td>
<td>Pliocene</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
<td>San Pedro</td>
<td>Pleistocene</td>
<td>Tr=Rup (Up Repetto Unconf)</td>
</tr>
</tbody>
</table>

DOE#1 Well Stratigraphic Column – Characterizes Pliocene Interval, Pico & Repetto Formations.
• Recovered 29 SWC and 9.5ft conventional core

• Correlated lithology with SFI#1 and SFI#2 wells

• Well TD in Pliocene based on micropaleontology correlation from SFI#2 well

• Sand porosities: 24-31%
• Sand permeabilities: 50-353md

• Shale porosities: 23-29%
• Shale permeabilities: <1-2md

• Pliocene gross sand thickness: 3000-3500ft
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3D Stratigraphic Overview

Stratigraphic layers of Wilmington Graben below 2,000ft depth
Project Area – Cross Sections for Geomechanical & Gas Migration Models

Tough2 model
FLAC model
Cross Section AA’ – Stratigraphy
Cross Section AA’ – Lithology

- Pliocene Repetto
- Miocene Puente

Lithology Index:
- Sand
- Sand/Shale Interbed
- Shale
- Silt
- Schist

SSL (ft):
- 0
- 1,000
- 2,000
- 3,000
- 4,000
- 5,000
- 6,000
- 7,000
- 8,000
- 9,000
- 10,000
- 11,000

Faults:
- Ploes Verder Fault
- THUFS Huntington Beach Fault
- Mesozoic Catalina Schist
Cross Section BB’ – Stratigraphy (2XVE)
Cross Section BB’ – Lithology
Estimated Storage Capacity

- 435 M MT: -3,000 to -6,000 ft
- 114 M MT: -6,000 to -12,000 ft

Sand:
- 177 M MT

Sand/Shale interbed:
- 61 M MT
- 53 M MT
Gas Migration Models – Concept (not to scale)

<table>
<thead>
<tr>
<th></th>
<th>AA</th>
<th>BB</th>
</tr>
</thead>
<tbody>
<tr>
<td># of cells</td>
<td>60,000</td>
<td>68,000</td>
</tr>
<tr>
<td>SW-NE x SE-NW</td>
<td>2,600 x 620 m (8,500 x 2,000 ft)</td>
<td>7,830 x 620 m (26,000 x 2,000 ft)</td>
</tr>
<tr>
<td>Model interval</td>
<td>-600 to -2,000 m (-1970 to -6560 ft)</td>
<td>-465 to -1720 m (-1525 to -5643 ft)</td>
</tr>
<tr>
<td>Injection interval</td>
<td>-1570 to -1600 m (-5150 to 5250 ft)</td>
<td>-1535 to -1555 m (-5036 to -5100 ft)</td>
</tr>
</tbody>
</table>
Pressure at Injection Cell for 1M MT/Yr, 0.5M MT/Yr & 0.25M MT/Yr - Injection for 5 years at BB’

- 1M MT/Yr --> exceeds fracture gradient
- 0.5M MT/Yr --> exceeds 1.2 original pressure
- 0.25M MT/Yr --> ~ 1.1 original pressure

In Situ Pressure @ 5045ft
- 1.0MT/Y (+ max. 37%)
- 0.5MT/Y (+ max. 20%)
- 0.25MT/Y (+ max. 11%)
Tough2 Models – AA’ Gas Plume

AA’ - 10 years

100 m (328 ft)

250 m (820 ft)
Tough2 Models – BB’ Gas Plume

BB’ - 10 years

200 m (656 ft)

500 m (1640 ft)
Conclusions so far:

- max. 250,000 MT/Y per well
- min. distance between wells: 1 mile
FLAC3D models have been developed along the two cross sections, A-A’ and B-B’

• Physical and thermal properties have been determined, and applied, from log data and core measurements from well DOE1 for A-A’ and log data from Shell OCS P-293_1 for B-B’;

• Pressure changes resulting from CO$_2$ injection, as determined by the migration models, have been input into models;

• Initial and boundary conditions have been set;

• The geomechanical model for the B-B’ cross section has been run for the first year of injection;

• The geomechanical model for the A-A’ cross section will be run next.
Cross Section AA’ – FLAC3D Model

A (SW)  (NE) A’

miles

- san-pedro
- pico
- repetto
- puente
- schist
Cross Section BB’ – FLAC3D Model

- **# of cells**: 30,000
- **SW-NE x SE-NW**: 86,000 x 100 ft
- **Model interval**: -75 to -10,500 ft
- **Injection interval**: -5036 to -5100 ft
- **Max Cell Size**: 600 ft X 400 ft
Cross Section BB’ – FLAC3D Model

Min Cell Size  50 ft X 16 ft
Cross Section BB’ –
Induced Vertical Displacement

- Virtually 0 Throughout Graben
- 0.07” Below Injection
- Greatest About 0.44” 1000’ Above Injection
- Could Be As Much As 0.33” Near Seafloor
Cross Section BB’ –
Induced Horizontal Stress

• Virtually 0 Throughout Graben
• Except In Few Thousand Feet Around Injection
• Greatest About 126 psi Of Compression At Injection
• Less Than 100 psi a Few Hundred Feet From Injection
Cross Section BB’ – Induced Shear Stress

- Virtually 0 Throughout Graben
- Except In Few Thousand Feet Around Injection
- Greatest Is Under 20 psi Near Injection
- Less Than 10 psi a Few Hundred Feet From Injection
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The Southern California Carbon Sequestration Research Consortium (SoCalCarb) is a collaborative research group bringing together scientists and engineers from more than 10 public agencies, private companies, and universities to identify and validate the best regional opportunities for keeping CO₂ out of the atmosphere, thereby reducing our anthropogenic impact on the climate.

Led by Terralog Technologies USA, with funding support by the US Department of Energy and the California Energy Commission, SoCalCarb is pursuing characterization studies for large scale CO₂ sequestration with rock strata and other potential storage pathways.
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All 9 DOGGR 1960’s wells open hole below surface casing.

All 6 Federal 1970’s offshore wells no well history data

3 New wells drilled in 2007 and 2010 all cased and cemented. No well leakage risk.

Problem wells will either need to be sealed or (preferably) those areas must be avoided completely.
• Acquired 175km of new seismic lines
• Drilled 1st characterization well into Pliocene
• Structure maps constructed for 4 horizons
• Geologic model near completion
• Initiated CO$_2$ migration modeling (TOUGH2): injecting 1 MT/yr results in pressure exceeding fracture gradient; 0.5 and 0.25 MMT/yr maintains pressure below fracture gradient
• Initiated geomechanical modeling (FLAC3D)
• Preliminary storage estimates >500 MMT
• Old well path may need to be sealed or avoided for large-scale CO$_2$ storage
• Source, sinks and pipeline interactive maps available online
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Next Project Steps

- Obtain drilling permits for a characterization well into Miocene formations;

- Continue applying geomechanical models to estimate stresses and fault activation risks due to large-scale CO₂ injection;

- Extend gas migration modeling out to 50 years;

- Complete engineering studies of LA Basin sources and transportation systems;

- Risk characterization and documentation;

Project Sponsors and Participants:

DOE NETL
California Energy Commission
City of Los Angeles, Department of Public Works
Southern California Gas Company (transport infrastructure)
Cal State Long Beach, Dr. Dan Francis (seismic acquisition)
Legg Geophysics (seismic interpretation)
USGS, Dr. Dan Ponti (cores and samples repository)
Terralog Technologies USA (geology, geomechanics, reservoir eng and drilling contract management)