From Concept to Reality: A Systematic Management Approach for Field Implementation of the Frio Brine Pilot Test

GCCC Digital Publication Series #05-04b

D. J. Collins

Keywords:
Frio Brine Pilot Experiment- Goals and Planning, Optimization, Risks, Real-Time Data Acquisition

Cited as:
Fourth Annual Conference on Carbon Capture & Sequestration

Developing Potential Paths Forward Based on the Knowledge, Science and Experience to Date

Geologic - Frio Brine Field Project (1)

From Concept to Reality: A systematic management approach for field implementation of the Frio Brine Pilot Test

Daniel J. Collins
dan.collins@sandiatech.com

May 2-5, 2005, Hilton Alexandria Mark Center, Alexandria Virginia
Shout Out to Co-authors

• Edward “Spud” Miller - Sandia Technologies LLC
• Susan D. Hovorka - Texas Bureau of Economic Geology
• Mark H. Holtz - Texas Bureau of Economic Geology
• Larry R. Meyer - Lawrence Berkeley National laboratory
Frio Brine Pilot Research Team

- Funded by US DOE National Energy Technology Lab: Karen Cohen, Charles Byrer
- Bureau of Economic Geology, Jackson School, The University of Texas at Austin: Susan Hovorka, Mark Holtz, Shinichi Sakurai, Seay Nance, Joseph Yeh, Paul Knox, Khaled Faoud
- Lawrence Berkeley National Lab, (Geo-Seq): Larry Myer, Tom Daley, Barry Freifeld, Rob Trautz, Christine Doughty, Sally Benson, Karsten Pruess, Curt Oldenburg, Jennifer Lewicki, Ernie Major, Mike Hoversten, Mac Kennedy; Don Lippert
- Oak Ridge National Lab: Dave Cole, Tommy Phelps Lawrence Livermore National Lab: Kevin Knauss, Jim Johns
- Alberta Research Council: Bill Gunter, John Robinson
- Texas American Resources: Don Charbula, David Hargiss
- Sandia Technologies: Dan Collins, Edward “Spud” Miller, David Freeman; Phil Papadeas
- BP: Charles Christopher, Mike Chambers
- Schlumberger: T. S. Ramakrishna, Austin Boyd, Nadia Muller, Pokey Mangum, and others
- SEQUIRE – National Energy Technology Lab: Curt White, Rod Diehl, Grant Bromhall, Brian Stratizar, Art Wells
- University of West Virginia: Henry Rausch
- USGS: Yousif Kharaka, Bill Evans, Evangelos Kakauros, Jim Thorsen
- Praxair: Joe Shine, Dan Dalton
- Australian CO₂CRC (CSRIO): Kevin Dodds and Don Sherlock
- Core Labs: Paul Martin, Russ Peacher, and others
Test site is located on the southwestern flank of Dayton Dome along the Upper Texas Gulf Coast

Dayton Dome is a salt piercement structure located within the Houston Embayment

The Injection and Observation Wells are located within a common fault block, bounded by faults to the southeast and northwest and the dome to the northeast
Frio Brine Pilot - Detailed Site Setting
Frio Brine Pilot - Site Area

- All of the nearby productive wells are from the Yegua Formation at +/- 8,800
- Tract is a 60 acre lease
- Lease Wells 1 through 5 were drilled in the 1950s, Well 6 was drilled by TARC in 1997
- Original plan was to recomplete the Sun-Gulf-Humble Fee No. 3 Well to the Injection Well, Modified plan resulted in installation of a new injection well for the Frio Brine Pilot
- Well to Well Distance ~ 100 feet
Evolution of Frio Pilot

<table>
<thead>
<tr>
<th>Year Quarter</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>43</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>44</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>46</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>48</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>49</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>51</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>52</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>53</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>54</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>56</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>57</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Activities:
- Complete Phase I Feasibility Study
- GEO-SEQ - organize research team
- Optimal site selection study
- Propose field study
- Site characterization- existing data
- Predictive modeling/Refine experiment
- Modify experiment design
- Model refinement
- NEPA permit preparation
- Injection permit preparation
- Modeling to support permits
- Site preparation, workover of Observation Well
- New Injection Well Installed
- Basin line data collected (aquifer test/geophysics)
- Predictive modeling with improved data
- CO2 Injection Experiment
- Post-injection measurements
- Calibration of models
- Closure

$ = DOE funding for field activities received
Project Planning/Management Goals

• Evaluate/Screen potential measurement, monitoring & verification technologies prior to site implementation (GEO-SEQ)
• Appropriately plan and sequence science experiments to minimize “competition” for the borehole(s)
• Optimize wellbore configurations for each phase of testing and minimize well recompletions
• Obtain continuous data during CO₂ injection for scientific analysis and regulatory compliance per permit conditions
Project High Risk Elements

• Quality of Cement Integrity/Isolation in the Observation Well from the Rework/Recompletion
• Drilling/Completion Problems in the Injection Well
• Quality of Cement Integrity/Isolation in the Injection Well
• No Interwell Communication or CO₂ Breakthrough at the Observation Well
• Downhole equipment failures during CO₂ Injection
• Large CO₂ Release on Location
Optimizing the Science

- Field methodologies had to be well thought out to ensure that “interference” between competing tests would not invalidate results of one or both tests.
- Experiments were potentially limited by casing restrictions and packer restrictions during CO$_2$ injection AND borehole “competition.”
Project Safety

- All field activities were performed under a site wide Health & Safety Plan (subtasks were added as addendums to the “site wide” HASP)
- Safety was considered a “key” element in Vendor selection
- Site safety meetings were held at the beginning of each shift and prior to all “non routine” activities
- A formal Process Safety Review (PSR) was held with the CO₂ supplier and pumping vendors prior to field mobilization
- Well flow back and CO₂ injection activities were monitored with surface meters/alarms
In Place Observation Well

- Observation Well is a former oil producer from the Yegua Formation at 8,800+ feet (1950s)
- The well casing was evaluated for integrity and plugged back to the Frio Formation in 8/03
- Circulating squeezes (5 sets) were performed to isolate the upper Frio Test Interval and Anahuac Formation (overlying seal) in 5/04
- Efficacy of squeezes were demonstrated by radioactive tracer survey follow perforation of the Frio C Sand
Observation Well Recompletion Detail

1. Conductor Pipe:
3. Protection Casing: 5-1/2" Set from surface to 8,964' (1952).
4. Squeeze Perforations:
   - 4,831' to 4,835' and 4,882' to 4,885'
   - 4,932' to 4,935' and 4,998' to 5,002'
   - 5,040' to 5,044' and 5,023 to 5,025'
   - 5,102 to 5,106' and 5,054' to 5,057'
   - 5,189' to 5,192' and 5,110' to 5,113'
5. Tubing String: Surface to 4,971'
   - 2-7/8" tubing Surface to 1,516'
   - Gas Lift Sub, 2-3/8" pup joint, 1,516' to 1,521'
   - 2-7/8" tubing, 1,521' to 4,948'
   - Pressure Gauge Sub, 2-3/8" pup joint 4,948'-54
   - Cross-Over Mandrel, 2" NU X 2-3/8", 4,954' to 4,960' (mandrel carries Sample Tube, Y and Check Valve, and Inflate Tube for Packer)
   - Inflatable Packer, Baker, w/3/8" pass-through SS line (sampler)
   - Inlet filter for Sample Tube
   - Wireline Re-entry Guide
6. Production Perforations: 5,014' to 5,034' w/ 4 shots per foot, 90 degrees phasing, 6.5 gram HMX charges, .245" entry holes, and 20" penetration. (8/2004)
12. Plug Back Total Depth: 8,600'
13. Abandoned Perforation: 8,810' to 8,914'
14. Total Depth Drilled: 9,516'

All depths reference RKB
KB = 12.7' above LMCF
G.L= 65'
Installation of a New Injection Well

- Allowed for a detailed characterization of the Frio C Injection Sand (whole core and geophysical logs)
- Ensured a “high-quality” cement bond across the Frio Test Interval, Anahuac Shale, and protection of usable sources of drinking water
- Costs of well installation were largely offset by reduced CO₂ volume and pumping time required for the experiment
New Injection Well Completion Detail

1) Conductor: 14" A-36, welded. Driven to +/- 118'.
2) Surface Casing: 9-5/8" 36-ppf J-55, EUE 8rd, ST&C. Set from surface to 2,668' in a 12-1/4" hole. Cemented with: 610 sks Lead Cement Class "A" 15:85 Poz Cement w/8% bentonite, +3% salt at 12.4 ppg, and 270 sks Tail Cement Class "A" w/0.2% R-3 + 0.005 g ps FP-6L at 15.6 ppg. Topped out with 12 bbls Class A w/2% CaCl.
3) Protective Casing: 5-1/2" 15.50 ppf, J-55, LT&C. Set from surface to 5,745' in a 7-7/8" hole. DV tool set at +/- 3,653-55'. Stage 1; Lead Cement - 206 sks Class "H" 35:65 Poz Cement w/6% bentonite +3% salt at 12.7 ppg, & Tail Cement 361 sks Class "A" w/10% NaCl at 16.4ppg. Stage 2; Lead Cement - 361 sks Class "A" 15:85 Poz Cement w/8% bentonite +3% NaCl at 12.4 ppg, & Tail Cement 352 sks Class "H" Cement w/2% NaCl at 16.4ppg.
4) Injection Tubing: 2-7/8", 6.5 ppf N-80 EU E 8rd. Surface to 4,880', with X-over 2-7/8" X 2-3/8" N-80 EU 8rd, Pup-Joint/Pressure Transducer Mandrel 2-3/8" N-80 EU 8rd 4,880' to 4889'.
5) Wireline: Externally strapped to injection tubing, Surface to Panex 1 320 pressure transducer attached externally with port at 4,886'.
6) Packer: Baker Hughes Hornet Mechanical Packer, 2-7/8" X 5-1/2", set at 4,889' to 4,897'
7) Production Perforations: Frio C Sand, 5,055' to 5,073' Owen Oil Tool, w/4 sqf, 90 deg phase, 6.5 gram HMX charges, 0.245" entry holes and 20" penetration
8) PBT: 5,634'
9) TD: 5,755'
Real-Time Data Acquisition System

• TCEQ Permit required continuous monitoring/recording of surface injection pressure, annulus pressure, injection rate, and injection volume

• The ASPEN Data Acquisition System allowed continuous monitoring/recording of:
  – Injection Well -> surface parameters - injection pressure, annulus pressure, injection rate, and injection temperature, and downhole parameters - pressure and temperature (Panex gauge just above the packer)
  – Observation Well -> surface parameters- pressure, annulus pressure, and temperature, and downhole parameters - pressure and temperature (Panex gauge just above the packer), and inflatable packer pressure
Real-Time Data Acquisition System - Continued

• The database was tied into a custom display package that allowed plotting of data and download of data during the experiment, without interrupting the data stream

• A web-based server location was set up to allow offsite “users” to access the plotting and downloading features so that experiment progress could be monitored from the office

• Real-time monitoring of surface and downhole conditions allowed Field Supervision to manage risk.
Summary

• The sequencing of experiments could be effectively managed to maximize scientific return within timing, budget, cross-test “interference”, and borehole constraints
• Addition of a new injection well to the project scope allowed more detailed site characterization, increased confidence of permitting, and ensured containment of injected CO$_2$
• The Frio Brine Pilot provides the “stepping stone” for larger, up-scaled demonstration projects