CO2 Capture Project®

CCP PROJECT FACTSHEET

CCP CO_2 STORAGE PROGRAM: Modular Borehole Monitoring design and field test

OVERVIEW

As part of its CCP3 Storage, Monitoring and Verification Program, the CCP has developed research goals to reduce the costs of well-based monitoring systems by designing a modular flexible package that can integrate the measurements that the site-specific monitoring strategy has identified as being most effective and critical. The CCP has been working with Lawrence Berkeley National Laboratory (LBNL) and the US Southeast Regional Carbon Sequestration Partnership (SECARB) to deliver a Modular Borehole Monitoring system, with the project coming to fruition and being tested at Citronelle Dome, Alabama, USA in 2012.

Understanding the processes initiated by the injection of large volumes of CO_2 in the deep subsurface requires a comprehensive monitoring strategy. While surface-based and other remote geophysical methods can provide information on the general morphology of a CO_2 plume, verification of the geochemical conditions and validation of the remote sensing data requires measurements from boreholes that are located in proximity to the plume.

Unfortunately, the high cost of drilling deep wellbores and significant engineering investment required for deploying permanent sensor packages constrains the number of dedicated monitoring boreholes and limits the technologies that can be incorporated in a single borehole completion.

By standardizing the suite of sensors and deployment package designs incorporated in a well-based CO_2 monitoring program, commercial scale CO_2 storage projects will benefit from a reduction of uncertainty in carrying out a monitoring & verification (M&V) program. Further advantages include reduced costs and a shortened timeline for fielding the M&V program by minimizing the engineering required for implementation. Operators will have the experience of previous users of the technology and can approach regulatory bodies with an M&V program that is founded on considerable experience and has proven performance specifications.

THE PROJECT

The Project has four main phases and is currently in Phase 4:

1. **Identify technologies and tools – evaluate potential monitoring instrumentation and identify the high priority tools/sensors**
   - Much of the learning curve and uncertainty in planning a CO_2 storage monitoring program can be removed by identifying the suite of technologies and tools that can be incorporated in a single integrated wellbore
2. **Design a modular deployment package which can accommodate the high priority items**
   - An engineering study to consider different options for constructing a modular deployment system. The commonality between each option is the need to deliver sensor systems to depths that can approach 4 km and temperatures of up to 130°C. The system also incorporates a structural backbone capable of transmitting the information gathered by the sensors as well as delivering the fluids, both hydraulic and sampled, downhole and to surface. Backbone options include integration with sucker rods, tubing, umbilicals or hybrid systems
3. **Perform engineering studies, identify and qualify suitable vendors and procurement support – guide the purchasing of components and provide the engineering/fabrication of a prototype**
   - Development of a fully detailed engineering design and fabrication of the modular deployment system to support the array of sensors. Fabrication costs are crucial in the engineering design
4. **Field Testing – support the field deployment of the prototype package**
   - The identification of a suitable field trial location and deployment of the Modular Borehole Monitoring (MBM) system has been a focal point of the project, to guide and demonstrate the principles of the design

RESULTS

Lawrence Berkeley National Laboratory (LBNL) was responsible for designing this innovative system, having considerable experience with a number of deployments of this type. A suitable field trial location was identified at Citronelle Dome, Alabama, where the US Southeast Regional Carbon Sequestration Partnership's (SECARB) Anthropogenic Test is being carried out to demonstrate CO_2 capture and storage from the near-by coal-fired power station, Plant Barry. Since August 2012, up to 550 metric tons per day of CO_2 has been captured and injected at Citronelle Dome.

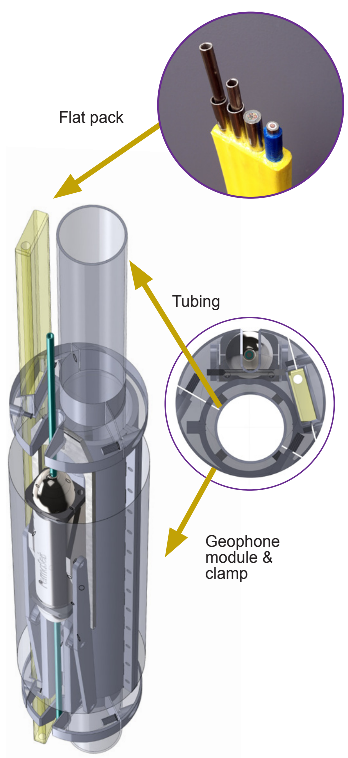
Production tubing provides the backbone for the Citronelle MBM system, covering the entire thickness of the Paluxy Formation and uses control line protectors located at each tubing joint. A hydraulic-set dual-mandrel packer at the top of the Paluxy formation provides zonal isolation and allows instrument lines to pass through the packer. An on/off coupling situated beneath the packer facilitates attaching the instrument package below the packer to the tubing string, eliminating the need to rotate the packer, due to the long instrument lines.

A polypropylene encapsulated flatpack is deployable from a spool that includes four elements: (1) a patent pending tube-in-tube U-tube geochemical fluid sampler; (2) a hybrid fiber-optic/copper heat-pulse cable for distributed temperature and acoustic sensing (DTS and DAS); (3) a coaxial cable for operating discrete downhole quartz pressure and temperature sensors, and (4) a tube-in-tube hydraulic line for actuating hydraulic-set geophone clamps. A separate orbitally welded, stainless steel encapsulated geophone cable, supplied by Paulsson Inc., supports an array of 18 borehole seismic pods (either 3-component or vertical) at 50 foot intervals, suitable for active-source and microseismic monitoring.

There are several unique elements to this system. Firstly, the tube-in-tube geometry for the U-tube system reduces the number of independent control lines. The U-tube sampler relies on two control lines, a drive line and a sample line for operation and is located at the top of the stacked sand horizons, so that it will preferentially sample the arriving buoyant gas. Both these lines are accommodated in a single tube-in-tube. Secondly an additional tube-in-tube is used for operation of the hydraulically operated geophone clamps. This permits the introduction and removal of the hydraulic fluid (commonly water or antifreeze) when the clamps are actuated.

Thirdly, a combined heating distributed temperature sensor (DTS) and distributed acoustic sensor (DAS) cable incorporates six 1000 V rated 20 AWG copper conductors as a means of heating the downhole fluids. Two multimode fibers are used for DTS monitoring, with the combined heater and DTS used to perform heat-pulse sensing. The DAS is a completely new instrument that uses a single mode fiber to monitor in-well acoustic noise to identify inflow and outflow locations.

Geophone pods and flatback by-pass



Pressure isolation & sensor cabling

Deployment

An informal partnership was formed between the CCP and SECARB, one of seven U.S. Department Energy-funded research programs on CO_2 storage, managed by the Southern States Energy Board. CCP member companies and LBNL worked closely with SECARB team members from Advanced Resources International, Denbury Resources, Electric Power Research Institute and Southern Company Services to deploy the MBM system at Citronelle in March 2012.

Frequent communication between team members and development of a thoroughly vetted well completion procedure, were important pre-cursors that led to a successful deployment of the MBM system. The use of the flat-pack construction, as compared to running individual lines, proceeded more quickly and was notably less risky than handling individual lines. High quality geophone data collected to date indicate that the clamps are operating as intended. Within this process the flatpack has proved robust and operationally efficient.

All of the components were tested and baseline measurements were conducted prior to the onset of CO_2 injection in August 2012. This baseline activity included the acquisition and characterization of reservoir fluid samples, testing of the heat-pulse/DTS system, a continuous record of reservoir pressure and the acquisition of baseline vertical seismic profiles using the borehole geophone array.

An early success for the MBM came in diagnosing well fluid entry above the packer. This was achieved by innovative use of induced heating through the heat-pulse cabling and temperature monitoring using the DTS. The depth-tied sensing of the temperature profile, together with pressuring up of the annulus, identified the perforation interval relative to the packer and verified fluid entry above the packer, establishing that an observed pressure bleedoff was not due to the MBM assembly. This data provided the Alabama authorities with the appropriate information for a decision to retain the tubing and MBM in the well. Subsequent fluid sampling was undertaken successfully with the U-tube.

ABOUT THE CO_2 CAPTURE PROJECT

The CO_2 Capture Project (CCP) is an award-winning partnership of several major energy companies working to advance the technologies that will underpin the deployment of industrial-scale CO_2 capture and storage.
To find out more visit www.co2captureproject.com